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MASS SPECTROMETER FOR D-REGION STUDIES

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SUMMARY

An instrument for the measurement of ambient ions in the D region of the atmosphere has been designed, built and tested in the laboratory. Its main components are a monopole mass spectrometer and a titanium getter pump. One unique feature is the wide mass range from mass 1 to approximately mass 400 in a scanning time of only 2.1 seconds. Laboratory tests have proven that the instrument has adequate sensitivity and resolution and it is ready for installation in a Tomahawk rocket.

This second part of the final report contains a detailed description of this flight prototype instrument, the test results and also all instructions for operation.

The first part of the final report will contain the theoretical background with references and the test results previously obtained with the laboratory model.

1. GENERAL DESIGN CONSIDERATIONS

Flight equipment for satellite applications has to be light and compact. The requirements for sounding rockets operating in the lower atmosphere, are less stringent. The expected performance of the mass spectrometer-getter pump system would be severely reduced by a reduction in the size of the instrument. Because major disadvantages would result in attempting to use a 6-inch o.d. package, the use of an 8-inch o.d. to mate the casing of a single stage Tomahawk rocket, has been selected. Since no other experiments were planned for the same rocket, weight consideration did not require a compromise with instrument performance. The flight will be to a maximum altitude of 100 km in order to obtain a long sampling time in the D region. This permitted the construction of an easily serviced instrument, which is of extreme importance for a first prototype. Standard ultra-high vacuum flanges and components have been used to allow disassembly and reassembly of the instrument. Valves, instead of pinch off tubes, have been provided for the pump-out and gas inlet line. All these measurements proved to be extremely valuable during the extended testing period when the instrument had to be disassembled and reassembled several times.

The total weight of the present instrument is 61 pounds. This figure does not include the nosecone and rocket skin, the batteries, the telemetry system and minor accessories. The inner structure of the instrument contributes only a small fraction to this weight as indicated in the following table:

Monopole mass spectrometer	4 lb
Ion pump	1 lb
Ion source and cover release	4 lb
Electronics	1 lb
Electronics housings	6 lb
Mass spectrometer housing	13 lb
Pump housing	10 lb
Main support tube and rocket mounting flange	22 lb
	61 lb

After completion of the laboratory testing, it would be possible to eliminate the large ultra high vacuum flange and replace it by a welded connection, reduce the wall thickness of the tubes, and to eliminate the valves and replace them by pinched off tubes. This would reduce the total weight to about one-third of its present value, without effecting the actual performance of the instrument.

The electronic packages have been designed for easy removal from the instrument during the bakeout procedure. These packages consist of two round boards, which carry only low voltages and can be exposed to the ambient atmosphere without danger of a glow discharge. The rest of the electronics is mounted in four sealed boxes, filled with air at atmospheric pressure, which are attached directly to the monopole instrument. They supply the high voltages necessary for the operation of the electron multiplier, the ion lens and the monopole filter. The fourth box contains the electrometer amplifier which is protected against high ambient humidity.

A simple ion source has been provided to permit checkout of the instrument in the laboratory and before flight. This ion source will be ejected during flight prior to the actual measurement of ambient ions.

The choice of a titanium getter pump in preference over the conventional zeolite absorption pump was triggered by the following considerations. Liquid nitrogen is not needed, which eliminates the possibility of contaminating the ambient atmosphere by evaporated ice from the filling aperture of the absorption pump. In addition, the absorption of the gas in the titanium getter pump occurs practically instantaneously, whereas the absorption in the zeolite pump is a much slower process. If the instrument is opened at medium altitude during flight, the pressure increase in the instrument is quite different for each type of pumps. In a getter pumped system the pressure increases gradually and continually after the instrument has been opened. In a cryogenic pumped system. the pressure increases rapidly upon opening and thereafter decreases slowly as the pump absorbes the initial large gas load and as the gas influx is reduced. The total absorption

capability of the cryopump cannot be utilized since this first pressure burst would cause a temporary blackout of the instrument. In both cases, the opening altitude has to be carefully chosen to avoid saturation of the pump. The titanium getter pump has the additional advantage of maintaining high vacuum in the system during extended storage periods of the instrument. Since during this period a part of the active titanium may have been consumed, it is advisable to deposit a new layer of titanium shortly before launch. The present system has been built with the intention of switching off the power to the pump shortly before launch and to use only the getter action of the freshly deposited titantium on the walls of the pump during the actual flight experiment. Proposals for improvement of this method are included in Section 7.

2. DETAILED DESCRIPTION OF THE MECHANICAL DESIGN

The instrument consists essentially of three parts, the main mass spectrometer, the titanium getter pump, and the ion source which will be ejected during flight. The instrument will be described with the aid of Figure 1which is a schematic cross section. In order to show as many details as possible, it was necessary to turn some parts into the cutting plane; this changed the relative position between several parts. Comparison with the actual instrument will easily permit identification of each component.

The interface between the mass spectrometer and the pump consists of two standard 8-inch diameter ultra-high vacuum flanges with a specially machined copper gasket (26) which holds the grid (27). This grid has been inserted between pump and mass spectrometer for two reasons: first, to shield the mass spectrometer electrically against the pump; second, to prevent tiny chips of titanium, which may occasionally peel off from the wall of the pump, to fall into the mass spectrometer.

The interface between the mass spectrometer and the ejectable ion source is shown by the heavy line (53). The rotable flange (10) is attached to the housing of the monopole instrument by two Truarc rings (47) and is used for three purposes:
(a) To fasten the ion source to the mass spectrometer.
(b) To hold the instrument in the center of the rocket skin by means of an O-ring (52), which is squeezed by the bolts (51) between the skin and flange. This rubber O-ring provides electrical insulation as well as shock mounting.
(c) The bolts (48) hold the four pressurized electronic packages which are located around the monopole mass spectrometer. These packages are sealed by the O-ring (60) (Parker No. 114) and by the rubber plates (59) underneath the covers (58).

The entire instrument is supported and mounted in the rocket by the tubular stand (36) which can be removed from the 8-inch flange without separating the flanges and venting the system. The two electronic boards (40) and (38), which are mounted by studs (39) on the plate (37) are located in the lower extension of this stand. The base ring (85) is part of the rocket housing and mates to a standard Tomahawk rocket. Between this ring and the mass spectrometer is an isolation plate (84) and isolated bolts are used to attach the stand to the ring. This permits charging the mass spectrometer structure to about -10 volts in regard to the shell of the rocket.

The space between the pump housing and the plate (37) contains a 1/2-inch valve which is required to evacuate the instrument before the electrostatic pump can be started. A large part of this space is void and can be used for other equipment. There is also space available on the electronics board (38).

2.1 Monopole Mass Analyzer (See Figures 1 and 2)

The basic dimensions of this instrument are as follows: Field radius = r_o = 0.200 inch. Rod diameter = 0.462 inch. Field length = 5.250 inches (this is the distance between the entrance and exit apertures). Both apertures are 0.062 inch in diameter and 0.062-inch long and are centered on the axis of the V-electrode. The air sampling hole has a diameter of 0.020 inch and is 0.030-inch long.

The mass spectrometer is mounted on four rods(18)which are supported by the rings (49) and (61). The ring (49) fits tightly into a step in the instrument housing. The ring (61) is held in place by the Truarc ring (62). The end-play is eliminated by two screws in the ring (49).

Since the ions have to be accelerated between the sampling orifice(54) in the housing of the instrument and the monopole filter it is necessary that the V-electrode is insulated from the housing. For this purpose 8 ceramic tubes (20) have been slipped over the rods (18) and are held in place by the Truarc rings (19). The ions are accelerated between the sampling orifice (54) and the grid (55) and decelerated in the focus electrode (56) and the entrance aperture (57). The V-electrode (17) consists of two bars which are bolted together and the supporting end plates which contain the entrance and exit apertures (57) and (63). The rod (16) is insulated from the V-electrode and from the end plates by ceramic spacers and is pressed against the V-electrode by the screws (23). These screws are insulated by the ceramic blocks (13). A cross section of the analyzer structure is shown on the left side. Attached to the V-electrode (17) are two shields (15) which eliminate the interference of the RF field with the electrometer. The rod and the V-electrode are heavily gold plated to reduce contact potentials. The beam is accelerated between the exit aperture (63) and the first dynode of the electron multiplier (64). The short tube in the center of ring (61) has been provided to reduce the possibility that stray ions from the pump can enter the electron multiplier. Another shield, not shown in the schematic drawing, has been provided around the anode end of the electron multiplier. The shield (25) is necessary to avoid interference between the RF voltage and the electrometer input.

2.2 Electrostatic Ion Pump (See Figures 1 and 3)

The inner pump structure is mounted on a triangular plate (69) which is pressed against the Truarc ring (68) by three bolts (67). Insulated from this plate by ceramic bushings (70) are four studs (71) which support the two filaments (74). The filaments consist of 10 turns of 10-mil diameter thoriated tungsten wire wound on a 1/16-inch diameter rod. The tungsten filament in spot-welded to nickel wires which are heliarc welded to the threaded studs. The filaments have to be well aligned and be accurately placed in the same plane as the two inner studs. The anode consists of the tungsten rod (76) with the titanium sleeve (75) which is held in place by two tungsten springs (77).

The anode is attached with two screws (31) to the feedthrough connector which is insulated from the plate (69) by the ceramic tubings (72). The lower end of the anode rod slides in the bar (80) which is also insulated by ceramic tubings (81) from the support plate (79) which is at housing potential. This lower support of the anode has been added to improve the shock resistance of the pump. The two grounded plates (32) and (79) with the tubes (33) are needed to obtain the proper electrostatic field. Plate (32) is attached to plate (69) by four studs (30) and plate (79) is attached to plate (32) by four studs.

Since it is anticipated that the anode structure will break when the rocket is launched, a grid (73) has been provided to prevent loose parts from falling into the mass spectrometer. The shield (29) has been added to prevent positive ions as well as electrons from migrating from the pump into the mass spectrometer. This shield is kept at anode potential. Not shown in the figure is a 1/2-inch ultra-high vacuum valve which is connected to the pump and used for rough evacuation of the system. A second connector is used for the ionization gauge and a third one is no longer in use and is sealed off.

2.3 Ion Source (See Figure 1)

An ion source is unnecessary for the measurement of the ambient ionic composition in the D-region of the atmosphere. However, for the laboratory checkout of the instrument it is convenient to incorporate an ion source. For this purpose, a very simple ion source has been provided. A rhenium filament (10-mil diameter helically wound with 3-1/2 turns on a 1/8-inch rod) is spot-welded to the feedthroughs (42) and (44). Electrons, emitted from this filament, are accelerated towards the anode (43) in axial direction. These electrons collide with gas molecules which are ionized and accelerated towards the opening of the mass spectrometer. A small fraction of them can pass through the entrance hole (54) which has a diameter of 0.020-inch and is 0.030-inch long. This small aperture allows the maintenance of a rather large pressure difference between the ionization chamber and the analyzer. The conductance of the hole is about 10 cm^3/sec. The total volume of the ion source with the glass type thermocouple gauge is about 60 cm^3. Therefore, the theoretical time constant is 6 seconds which is in good agreement with the experiment.

The housing of the ion source consists of two standard ultra-high vacuum flanges which are sealed with a copper gasket. Between the ion source and the housing of the mass spectrometer is a V-shaped gold seal(41) (Parker No. 8882-1002-00). The ion source is pressed with the release bolts against the housing of the mass spectrometer. Connected to the ion source are a thermocouple gauge and a 1/4-inch ultra-high vacuum valve to introduce gas for calibration purposes.

VIEW A-A
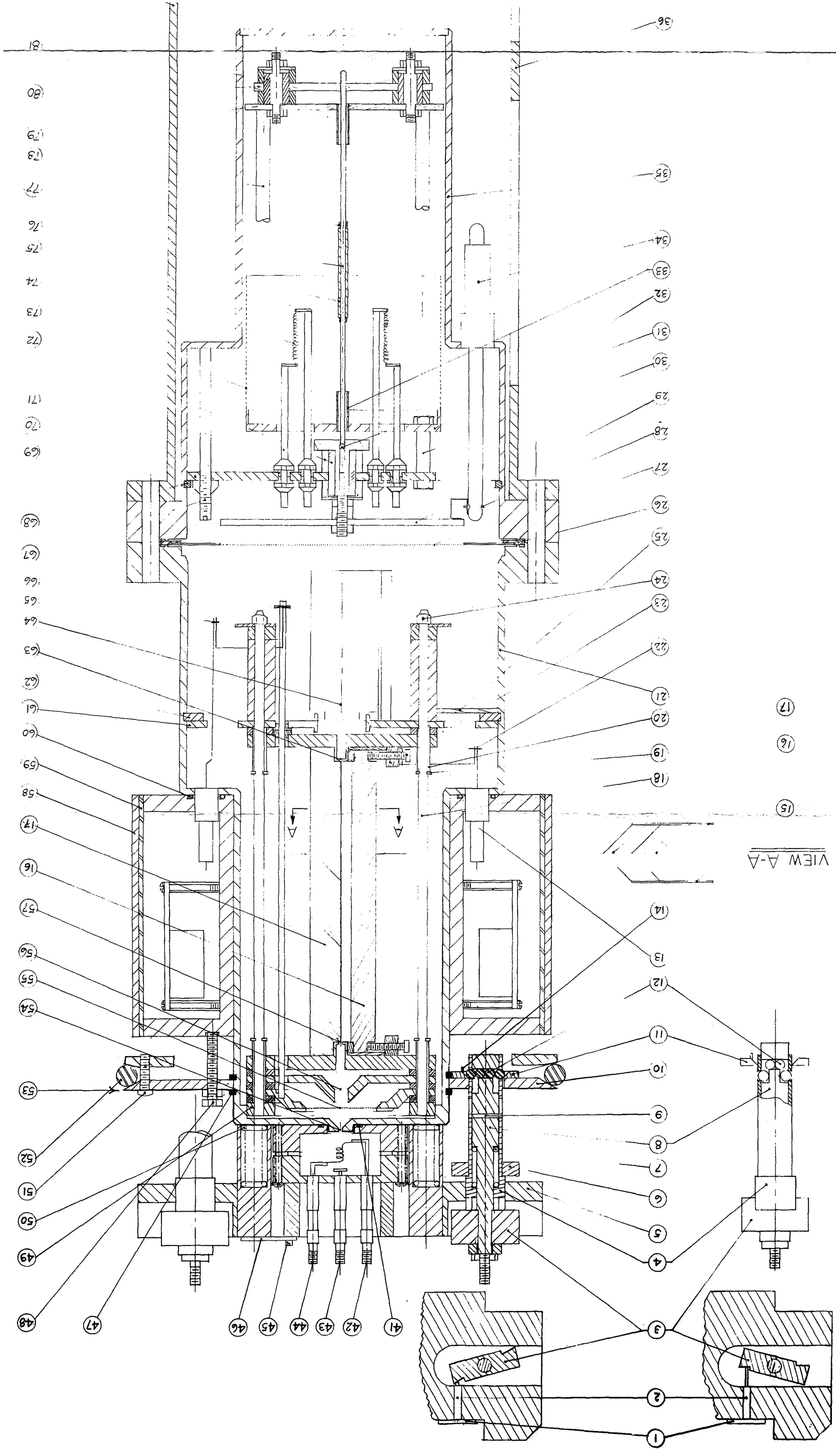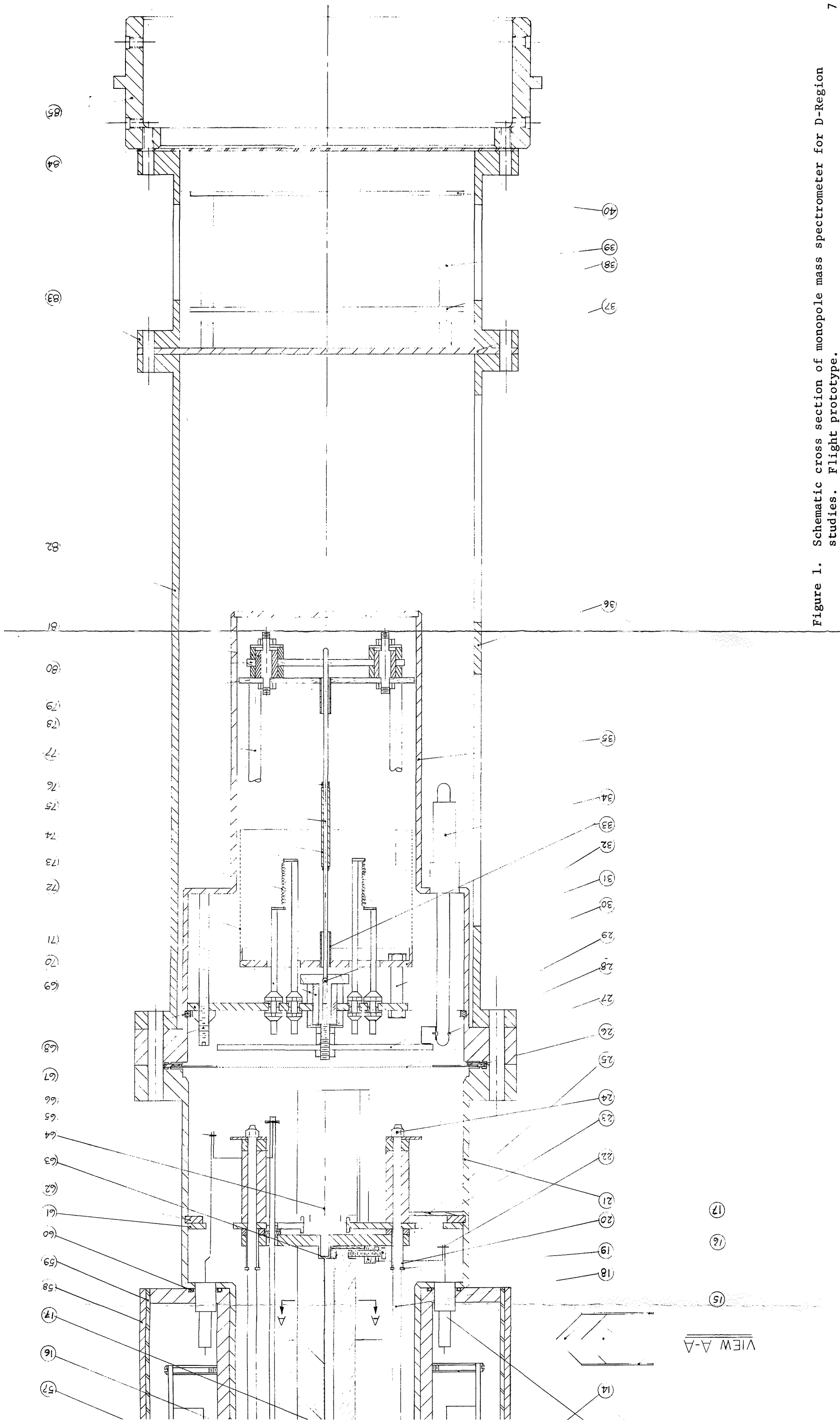
Figure 1. Schematic cross section of monopole mass spectrometer for D-Region studies. Flight prototype.

Figure 2. Inner structure of monopole analyzer. The rod and V-electrodes
with the ceramic mounting blocks are visible in the center of the
figure. The electron multiplier has been removed.

Figure 3. Inner structure of the electrostatic ion pump. The two filaments and the anode with the titanium rod are visible. The lower support of the anode has been removed.

2.4 Cover Release Mechanism (See Figure 1)
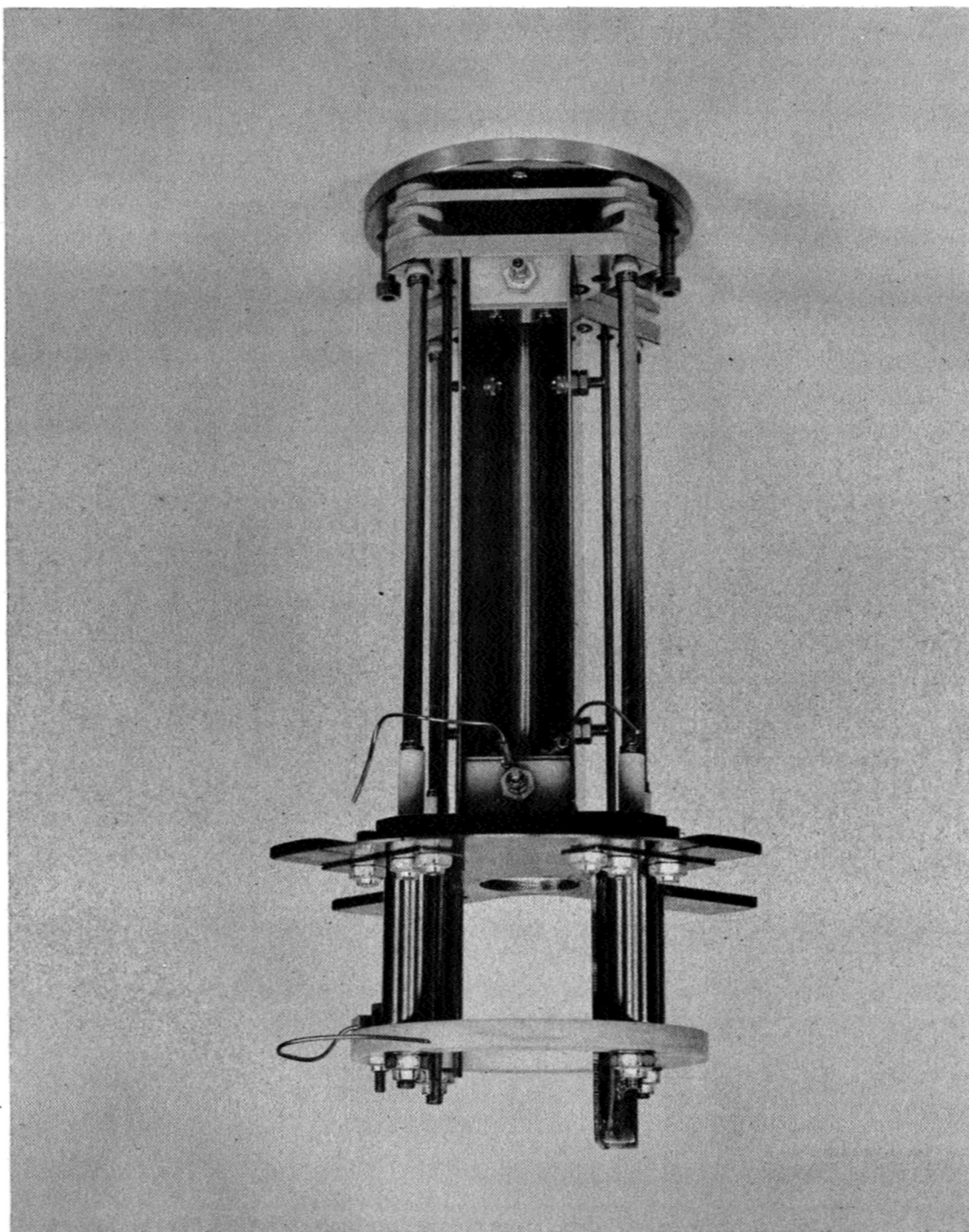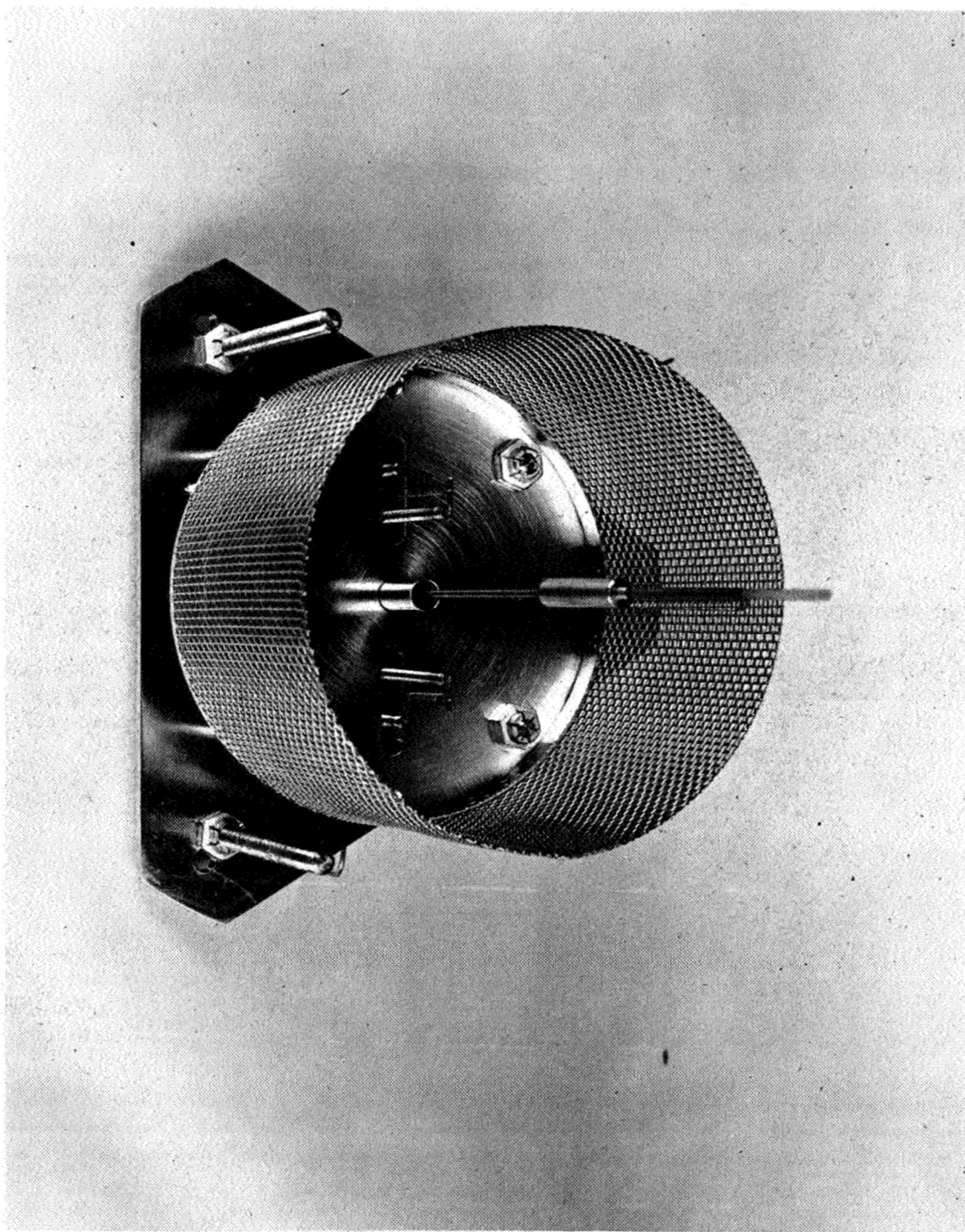
The following design objectives had to be met:

(a) The ion source shall be easily demountable for cleaning and filament replacement.

(b) The whole system shall be bakable. This excludes the use of rubber gaskets. Metal gaskets have to be used throughout.

(c) The release bolts should be capable of providing the large force necessary to seal metal gaskets.

(d) The cover release shall be independent of the split nose-cone ejection.

(e) Vibration of the instrument shall not cause any accidental release of the cover.

(f) Loading of the device with the explosive actuators has to be performed after the bakeout.

These objectives have been met by the following design: The top plate (5) is clamped against the ring (10) by two release bolts. The release bolt on the main drawing is shown in the locked position. The one on the very left side in the released position. These bolts consist of a piston (8) and a cylinder(4). The piston slides in axial direction and is prevented from turning by the pin (9). The hole through the lower part of the piston and cylinder contains 4 balls (12) which extend beyond the cylinder, thus preventing the cylinder from slipping through the washer (11). The block (3) rests against an extension of the cylinder and prevents the spring (7) from pushing the cylinder down. Each of the two release bolts is attached to the main plate (5) by means of two screws which press the plate (6) upward. The block (3) is rotable around the piston. This rotation is accomplished by two explosive actuators (2) (Atlas Model 1MT 114) which are held in place by the terminal board (1). The four explosive actuators (two for each bolt) have to be connected in parallel. If the explosive actuators have been fired, as it is shown on the left side of the drawing, the block (3) is turned and falls into a recess of the cylinder (4). The spring (7) pushes the piston downward. The inner balls roll against the outer balls and the outer balls fall into a recess of the piston. This releases the bolt from the washer(11). The two springs (50) eject the whole cover above the interface (53).

During the tests, one explosive actuator was sufficient to release the bolts. However, two have been provided in order to increase the reliability. It has been found that the alignment of the 4 balls (12) is rather critical. If the piston in the locked position is too low, the friction between the block (3) and the cylinder (4) is too large and the explosive actuators may not be powerful enough to turn it. If the piston is too high, the block (3) is lifted up from the cylinder (4) and turning becomes quite easy. In this case the spring (7) is not powerful enough to

push the piston down. The block (3) shall have considerable friction, but still be turnable by hand or with the aid of a screwdriver. 'Be careful when testing this, because excessive turning may release the bolt and break the vacuum! Since careful adjustments have been performed during the extensive tests of this device, it is not expected that further adjustment will be necessary.

2.5 Gauges

According to the contract requirements, one glass Bayard Alpert gauge and and one glass thermocouple gauge (Hastings-Raydist Model DV-20) have been supplied. Both gauges are fitted with the Varian-type ultra-high vacuum couplings, Model No. 954-0059.

Since it is undesirable to use glass gauges for flight hardware, an attempt has been made to provide metal gauges. The inner structure of a standard thermocouple gauge (Hastings-Raydist Model DV-6M) has been installed in a bakable metal housing. This gauge worked well, but the delicate filaments did not survive the vibration test. Nevertheless, it would still be better suitable for the flight instrument since this gauge is only used for testing and not during the flight. It would permit checking the vacuum right up to launch time and has the great advantage that it does not have to be removed before launch. The glass type thermocouple gauge is now attached to the ion source. Since it may break off, it has to be removed before launch of the instrument. A good glass blower will be able to pull off the gauge without admitting air to the system.

Earlier experiments with a "thermistor" type vacuum gauge, (General Electric Model 22GT300) were not satisfactory because even the moderate heat from the ion source filament has caused an excessive zero drift. Since any pumping action is undesirable during the testing of the instrument, it is not possible to use a Penning type gauge or a small appendage ion pump. The best choice is a Pirani type gauge which could be especially built for this purpose.

An ionization gauge has also been built and is still attached to the instrument. This gauge is of extremely simple construction. It consists of three identical filaments each of which can be used either as electron emitter or as ion collector or an electron collector. Even if one or two filaments have burned out, they can still be used as ion and electron collector with practically no change of sensitivity. Originally this gauge worked very well. It has been roughly calibrated by comparison with a standard Bayard Alpert gauge. The ion current is approximately 10^{-9} ampere at a pressure of 10^{-6} torr for 10^{-14}-ampere emission current.

If the filament current is kept constant, the electron emission current decreases with increasing pressure. In order to avoid the need for manual regulation, a simple emission regulator (see Figure 4) has been built and supplied with the instrument. During the first tests of the gauge, the filament was heated by ac current. However, it was found that the heat capacity of the thin filament is so small that the electron
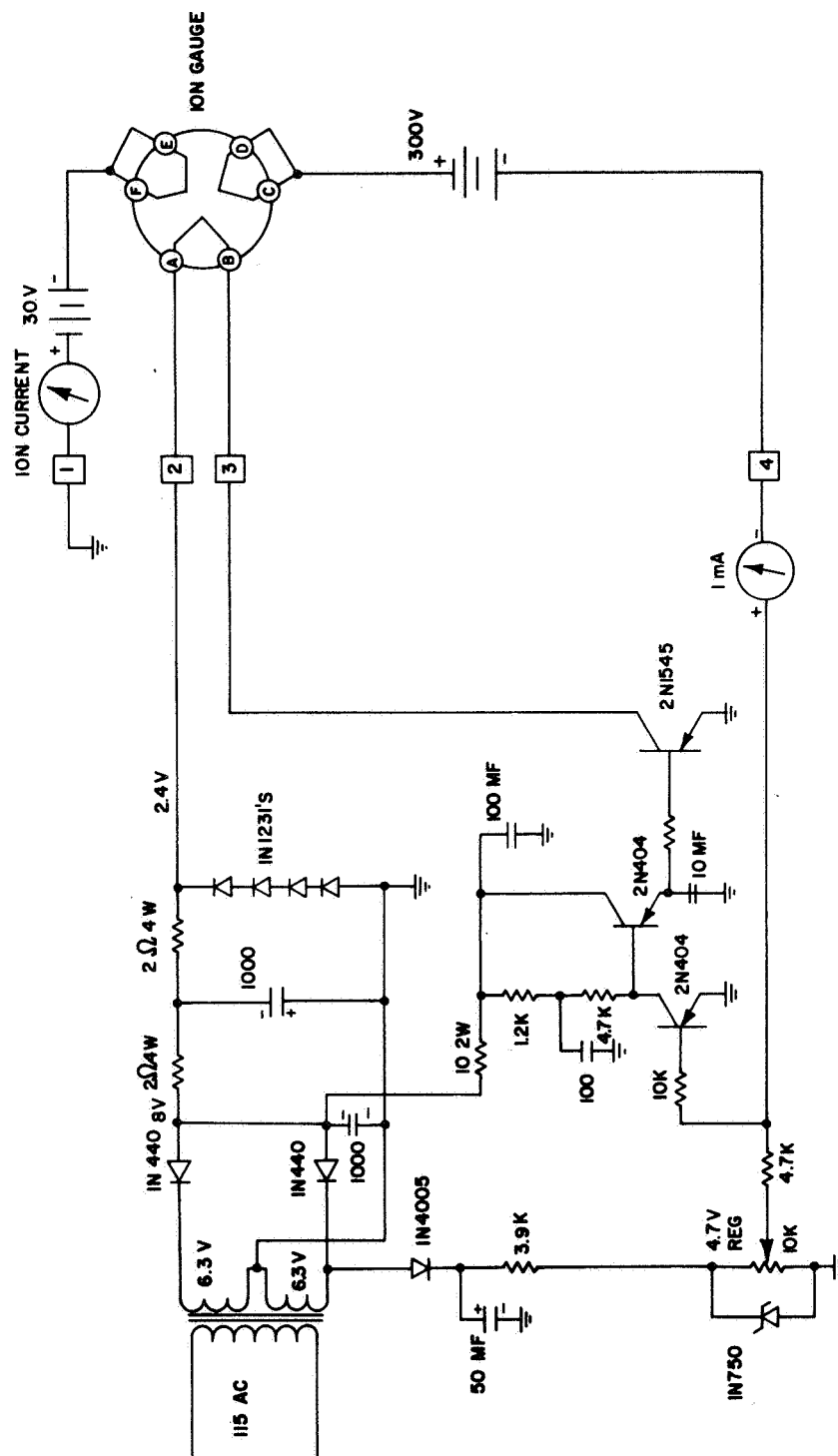
Figure 4. Ion gauge control D-Region spectrometer.

emission current was strongly modulated with 120 cycles per second. This modulation had a detrimental effect on the emission regulation. Therefore, dc current is now used to heat the filament.

Unfortunately, during the evacuation of the instrument an accident occurred. The motor of the fore pump burned out and air rushed through the diffusion pump into the system, thus contaminating the entire instrument with oil vapor. At this occasion, one of the three filaments of the gauge burned out. The gauge has been washed with acetone and still performed well with the remaining electrodes. However, after the following high temperature bakeout, a large leakage current developed between the ion collector and the housing, as well as between the electron collector and the housing. Probably remaining hydrocarbons have been decomposed during the bakeout and have formed a conductive carbon layer on the insulators. The gauge is still usable, if the leakage currents are subtracted from the total currents. Therefore, the gauge has been left on the system.

The glass type Bayard Alpert gauge, which has been supplied as a spare part, can only be used for laboratory testing, since it will not survive the rocket launch. It would be rather difficult to pull off and seal the 3/4-inch glass tube without admitting air into the system. Therefore the use of a metal gauge is essential for the reliable operation of the instrument and the replacement of the present gauge with a new gauge of the same type is highly recommended.

3. ELECTRONICS FOR MONOPOLE MASS SPECTROMETER

The electronic circuits for the D region mass spectrometer can be subdivided in the following major functional blocks:

3.1 Sweep generator

3.2 RF supply

3.3 High voltage supply

3.4 Grid and focus supply

3.5 Electrometer amplifier

3.6 Low voltage supply

The circuit elements are mounted on two 6-inch round boards and in four air-tight enclosures. The air-tight enclosures are designed to retain normal atmospheric pressure during flight, thus preventing arc-over of the high voltage connection at reduced atmosphere pressure. The description is based on the electronic circuit diagram, Figure 5.

The spectrometer requires a power source of plus and minus 28V against instrument housing. The voltages are supplied through A2J1.

> USE EXTREME CARE IN MAKING THESE CONNECTION. THE WRONG
> POLARITY IN EITHER ONE OF THESE CONNECTIONS WILL RESULT
> IN COMPLETE DAMAGE OF THE ELECTRONIC UNITS!

The instrument can be turned off and on by means of the power supply switches or by disconnecting A2J1. While either voltage can be turned on first it is not advisable to leave only one voltage connected for any extended period of time.

The total power consumption of the instrument at the extended mass range is for the

+ 28 volts supply: 230 milliamperes	or	6.5 watt
- 28 volts supply: 32 milliamperes	or	0.9 watt
total		7.4 watt

The power consumption is quite reasonable for this rocket-borne instrument which has to be operated for only a few minutes. For a satellite instrument it would be possible to reduce the power consumption considerably, especially if the extended mass range is not needed.

The voltage which has to be supplied to the rod of the monopole filter against the V-electrode consists of a superimposed ac and a negative dc voltage. During the regular scan for the low mass range, the dc voltage is proportional to the ac voltage and derived by rectification of a fraction of the ac voltage. For the extended mass range, the ac voltage is kept constant and the dc voltage reduced by discharging a capacitor. The waveforms of these voltages together with the voltages of other test points are shown in Figure 6.

An additional dc voltage of -13.3 volts is supplied to the V-electrode against the housing. This voltage is essentially the ion energy in the monopole filter. The actual ion energy is slightly higher by the initial energy of the ions in the entrance aperture. However, due to the high pressure in the shock wave in front of the instrument, most of the energy of the ambient ions, which originated from the speed of the rocket and from the potential difference between rocket skin and entrance aperture, will be lost in multiple collisions. Only at the highest altitude of the D-region the initial ion energy might become noticeable in a slight increase of sensitivity and decrease of resolution.

3.1 Sweep Generator (See upper left half of Figure 5 and right half of Figure 7)

The amplifiers AR1, AR3, and Q3 generate the control voltages for the RF modulator and amplifier. AR1 is a linear ramp generator. The slope of the ramp depends on the size of the 1-microfarad capacitor, the 1.8M input resistor and on the +15 volt applied voltage. With the present values, the AR1 output reaches -10 volts in 1.4 seconds starting from zero volt. The voltage comparator AR2 compares the generated ramp voltage with a -10 volt reference voltage. When the two voltages become equal, the comparator switches state and energizes the relay K1 thereby applying the fixed -10 volts to the RF control amplifier AR3. From this moment on, the ac voltage is kept constant and the extended mass range is started. At the same time a second contact of relay K1 opens, thereby removing the supply of the dc voltage to the bottom of the coil L2. The 0.02 microfarad capacitor between this point and ground is discharged through the 8.2-megohm resistor(which is connected to +28 volts) in order to remove the negative charge completely in about half a second. This produces the slope of the dc voltage as shown in the second line of Figure 6.

At the same time that relay K1 is energized, a timing circuit is started which controls the length of time (0.7 second) allocated for the scanning of the extended mass range. The unijunction delay circuit consists of the transistor Q8 and the 2.2-megohm resistor with the 1-microfarad capacitor which values determine the delay time.

After 0.7 seconds the unijunction fires and applies a trigger voltage to AR5 which is connected as a one shot multivibrator of approximately 10 milliseconds duration. AR5 switches from +15 to -15 volts. This 10-millisecond pulse is applied to Q1 which discharges the AR1 feedback capacitor, thus starting a new sweep cycle. Since now the sweep voltage is smaller than 10 volts, the voltage comparator de-energizes relay K1, thus reconnecting the sweep voltage to the control amplifier AR3. This 10-millisecond pulse is also introduced directly to the control amplifier AR3 to interrupt the RF voltage and to allow enough time for the rectifier filters to discharge before the start of the next cycle.

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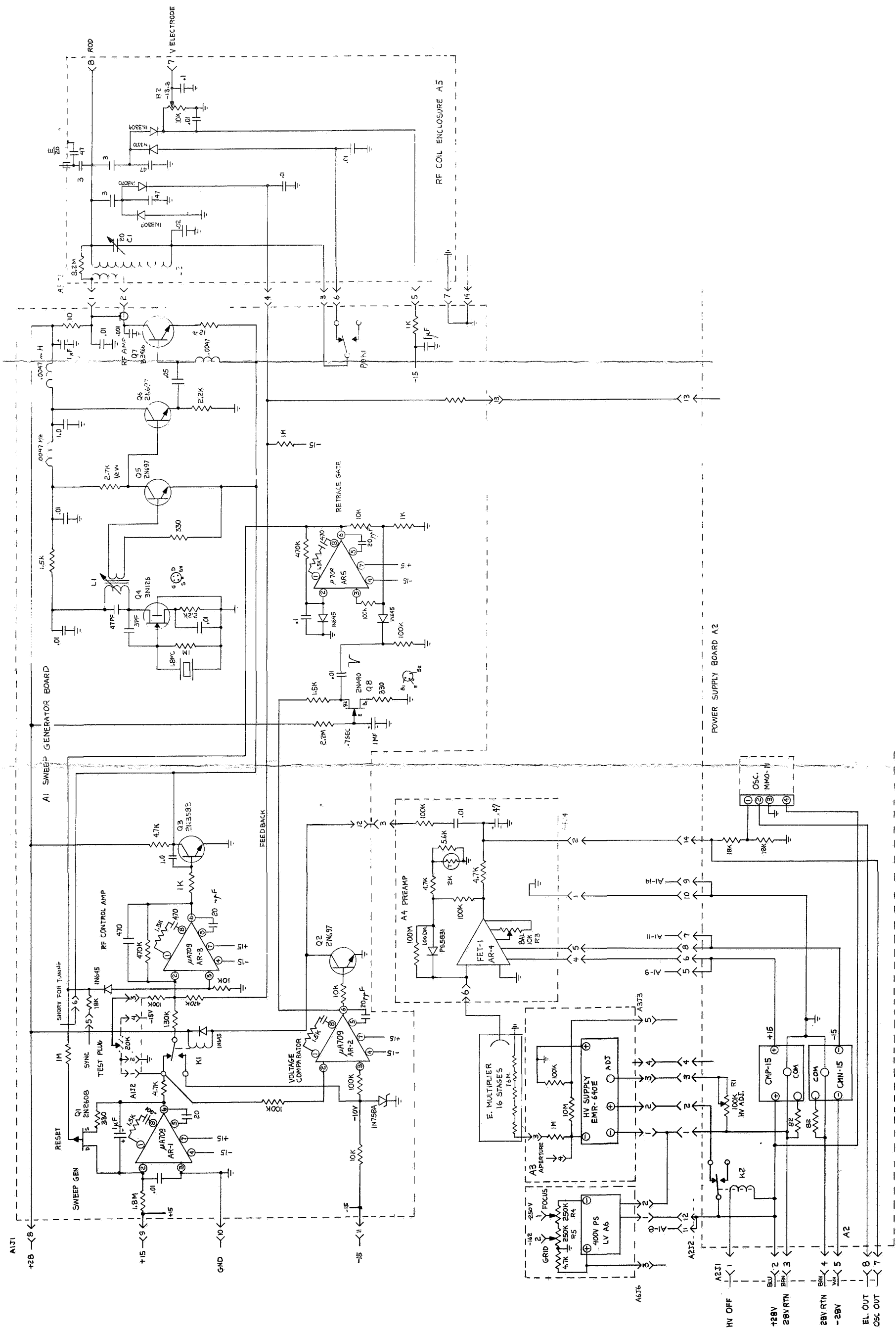
Figure 5. Electronic Circuit Diagram.

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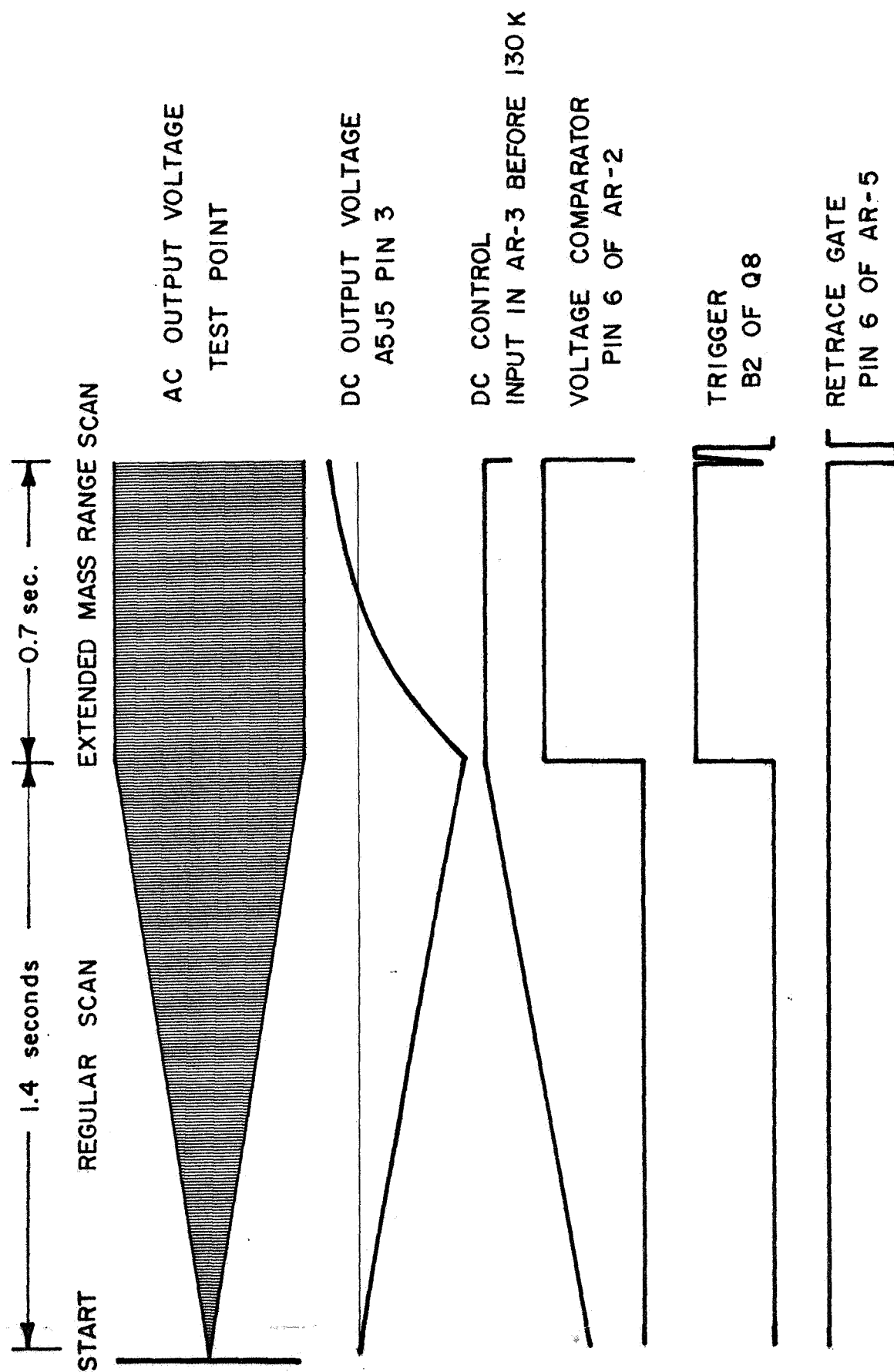
Figure 6. Typical voltage wave forms for one scan of the D-region mass spectrometer.

START   REGULAR SCAN   EXTENDED MASS RANGE SCAN

|← 1.4 seconds →|← 0.7 sec. →|

AC OUTPUT VOLTAGE
TEST POINT

DC OUTPUT VOLTAGE
A5J5 PIN 3

DC CONTROL
INPUT IN AR-3 BEFORE 130 K

VOLTAGE COMPARATOR
PIN 6 OF AR-2
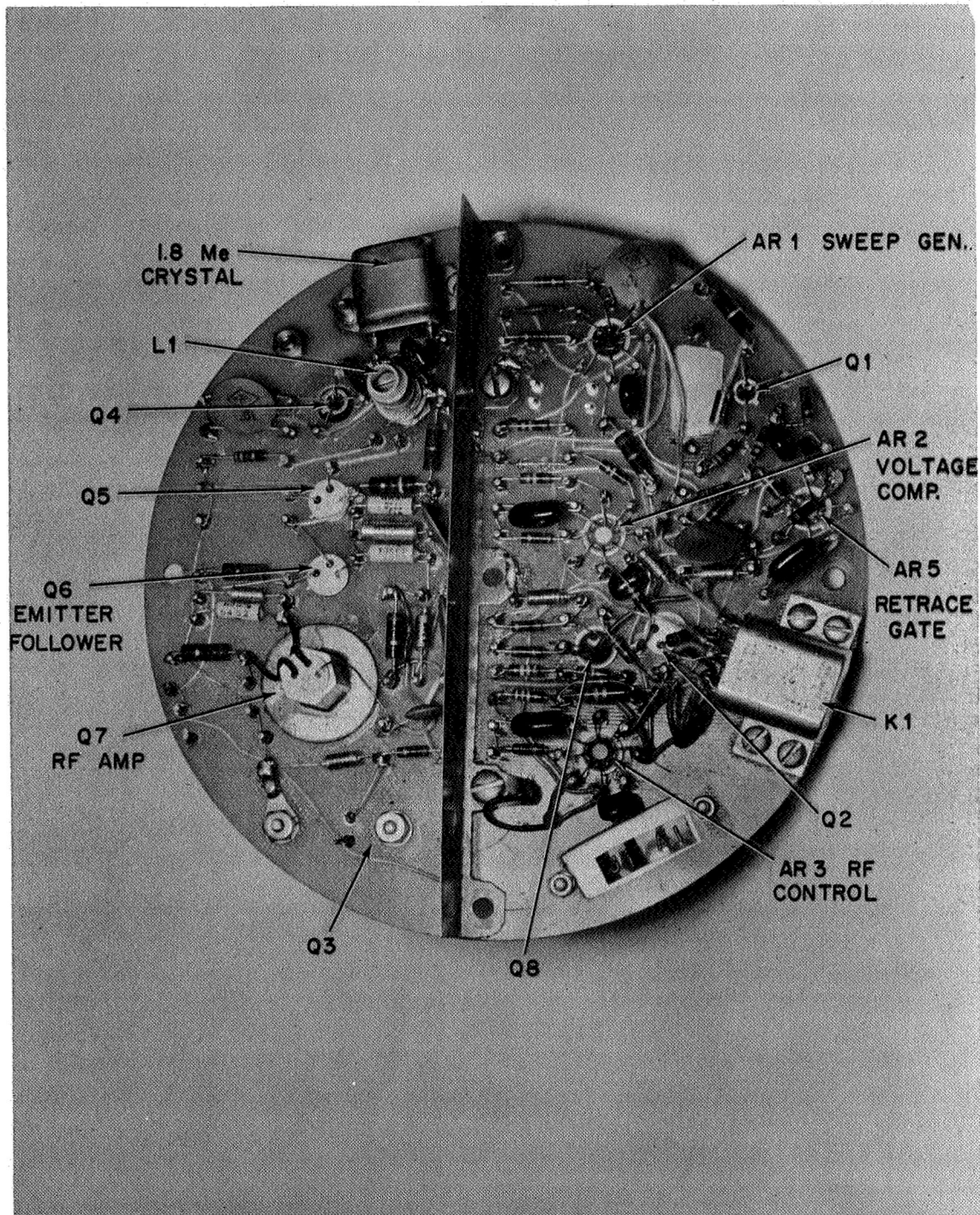
TRIGGER
B2 OF Q8

RETRACE GATE
PIN 6 OF AR-5

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Figure 7. Sweep generator board.

3.2 RF Supply (See right upper half of Figure 5 and left half of Figure 7 and Figure 8)

Q4 is a crystal controlled 1.8-megacycle oscillator in which the crystal operates in the parallel mode. The collector's RF voltage, stepped down for impedance matching, is applied to an isolation amplifier Q5 followed by an emitter follower Q6. Q7 is the final RF amplifier. Both Q5 and Q7 are modulated by the control amplifiers Q3 and AR1. The RF coil is located in an airtight enclosure and is link coupled to the collector of Q7. A portion of the RF voltage is rectified by two sets of voltage doubler RF diodes. One of the rectifiers supplies the negative dc voltage proportional to the RF voltage which is required to operate the monopole mass spectrometer. The other rectifier supplies a positive dc voltage used in a feedback loop for the regulating amplifier. The operation is as follows:

The summing junction of the operational amplifier AR3 receives the ramp voltage through the 130 K resistor and also a sample of the rectified RF voltage through the 470 K resistor. The output of the amplifier by means of Q3 modulates the RF amplifier Q7 so that the voltage at the input of AR3 is always close to zero, resulting in an RF voltage proportional to the ramp voltage.

This provides an amplitude swept RF voltage between about 1 and 560VPP with very good linearity and stability. The unregulated RF output is approximately 900VPP thus providing more than ample reserve for the regulator.

RF Tuning. — The tuning of the RF output circuit is not critical and should not be necessary unless the instrument was completely disassembled. Small detuning has no effect on the mass spectra as long as the regulator is operating. Large detuning will reduce the mass range and change the mass scale. This is the result of a change of the dc/ac voltage ratio caused by the appearance of harmonics.

The RF tuning capacitor is accessible through a screw hole on the cover of the RF enclosure. A test point for oscilloscope monitoring is on the right side of the enclosure and when used with a X10 probe (10PF) will give 1/20 of the RF voltage at the coil.

(a) To tune the RF coil connect the oscilloscope to the RF test point on the side of the RF enclosure. The oscilloscope probe does not load the RF circuit and can be connected to the test point any time it is required.

(b) Disable the feedback circuit and sweep by grounding pins 1 and 6 of A1J2 (test plug). A tuning test plug is wired for this purpose and can be inserted in the test connector.

(c) Using a small insulated screw driver tune the RF coil for maximum oscilloscope output. The screw driver can be insulated by a piece of teflon spaghetti slipped over the blade. If the screw driver blade touches the RF enclosure and the tuning capacitor the RF rectifier diodes may be damaged!
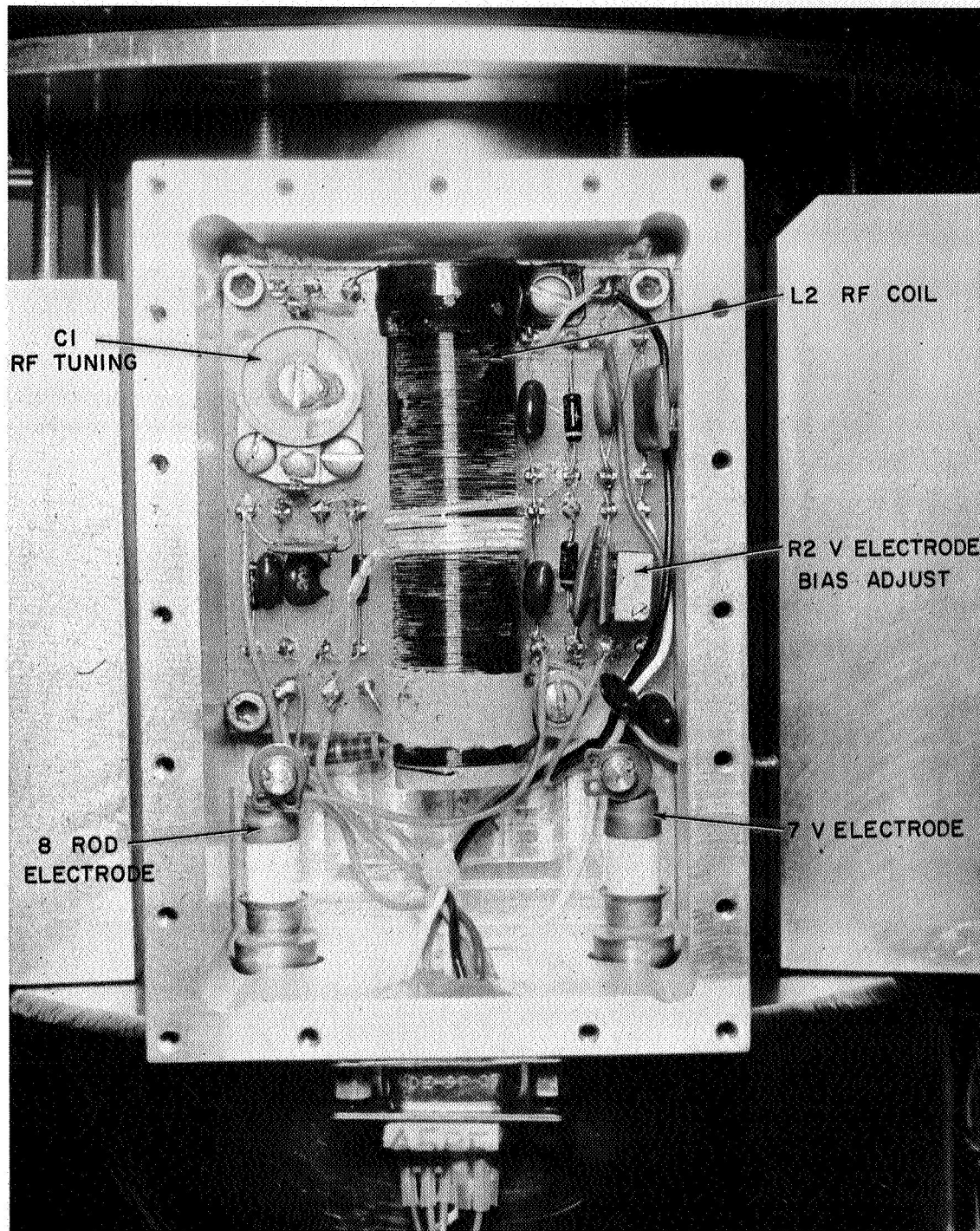
Figure 8. RF coil enclosure.

3.3 High Voltage Supply (See Figure 9)

The high voltage supply used for the multiplier is an EMR 640E module, capable of producing a regulated output between 1500 and 3500 volts at 240 microamperes. The multiplier is normally operated at approximately 2500 volts. The high voltage can be adjusted by means of a 100 K pot located on the low voltage board.

A fraction of the voltage (1/100) is brought out of the airtight enclosure through pin 5 for monitoring purposes.

3.4 Grid and Focus Supply (See Figure 10)

This supply is a TEC module No. 5570114 unregulated supply giving an output of 400 volts at 0.75 milli-ampere. Two pots are located within the enclosure for the voltage adjustments of the grid and focus electrodes. Normal voltages are -162 volts for the grid and -250 volts for the focus.

3.5 Electrometer (See Figure 11)

The electrometer amplifier consists of a Nexus FET-1 operational amplifier module AR4 with a log-diode feedback element. AR4 is a high gain (20000) high input impedance (10^{11} ohm) amplifier. The main feedback path consists of the log diode shunted by a 10^8 ohm resistor. The log diode is a special product of TRW, Inc. This diode has a dynamic range from 10^{-11} ampere to 10^{-4} ampere and an output from 5 millivolts to 530 millivolts; $V = 68$ mV x $(11 - \log i)$ with a temperature coefficient of -3 percent per C^o. The amplifier feedback is reduced by a factor of 0.058. This factor is made dependent on the temperature to compensate for the temperature coefficient of the diode. For this purpose, the 2 K thermistor has been incorporated which has a temperature coefficient of -4 percent per C^o.

The final output voltage U is reduced by the 4.7 - 18 - 18K resistor chain to 0.88 of the output of AR4. Therefore, the total voltage gain is 0.88/0.058 = 15. The current scale is given by

$$ i = \frac{U}{15} \times 10^{-8} + 10^{-(11-U)} - 10^{-11} \text{ amperes} $$

which has been found to be in good agreement with the calibration (see Figure 18). If U is smaller than 1 volt the second term is small compared to the first one and the scale is essentially linear. If U is larger than 4 volts, the first term is small compared to the second one and the scale is essentially logarithmic. The advantage of this scale is that it has enough sensitivity to see even single ions with a time constant short enough to permit fast scan. The middle part of the intensity scale is expanded and permits a more accurate measurement of those peaks which are most likely to be expected. If there are occasionally very large peaks, they will stay "on scale" and can be measured on the compressed logarithmic part of the intensity scale.
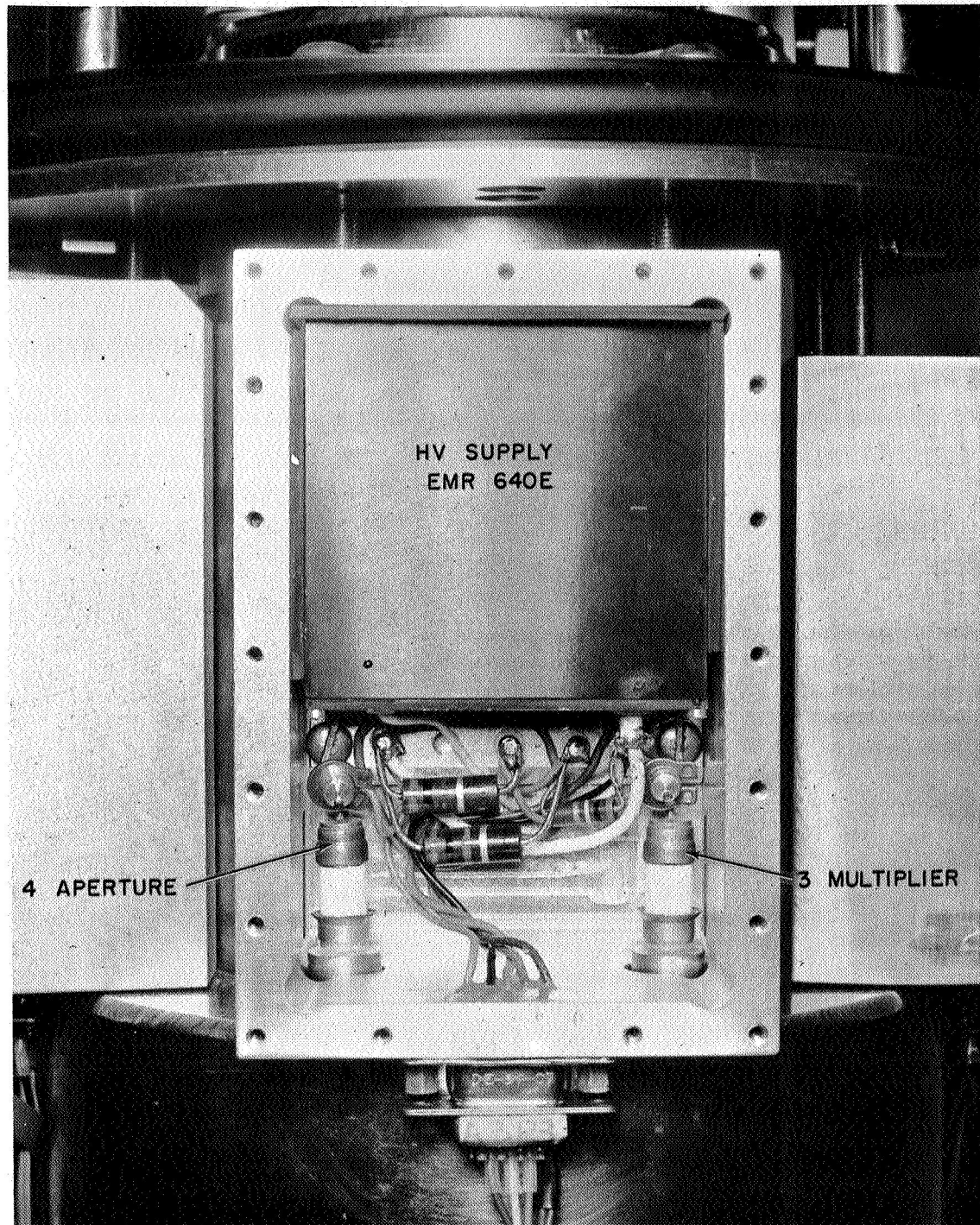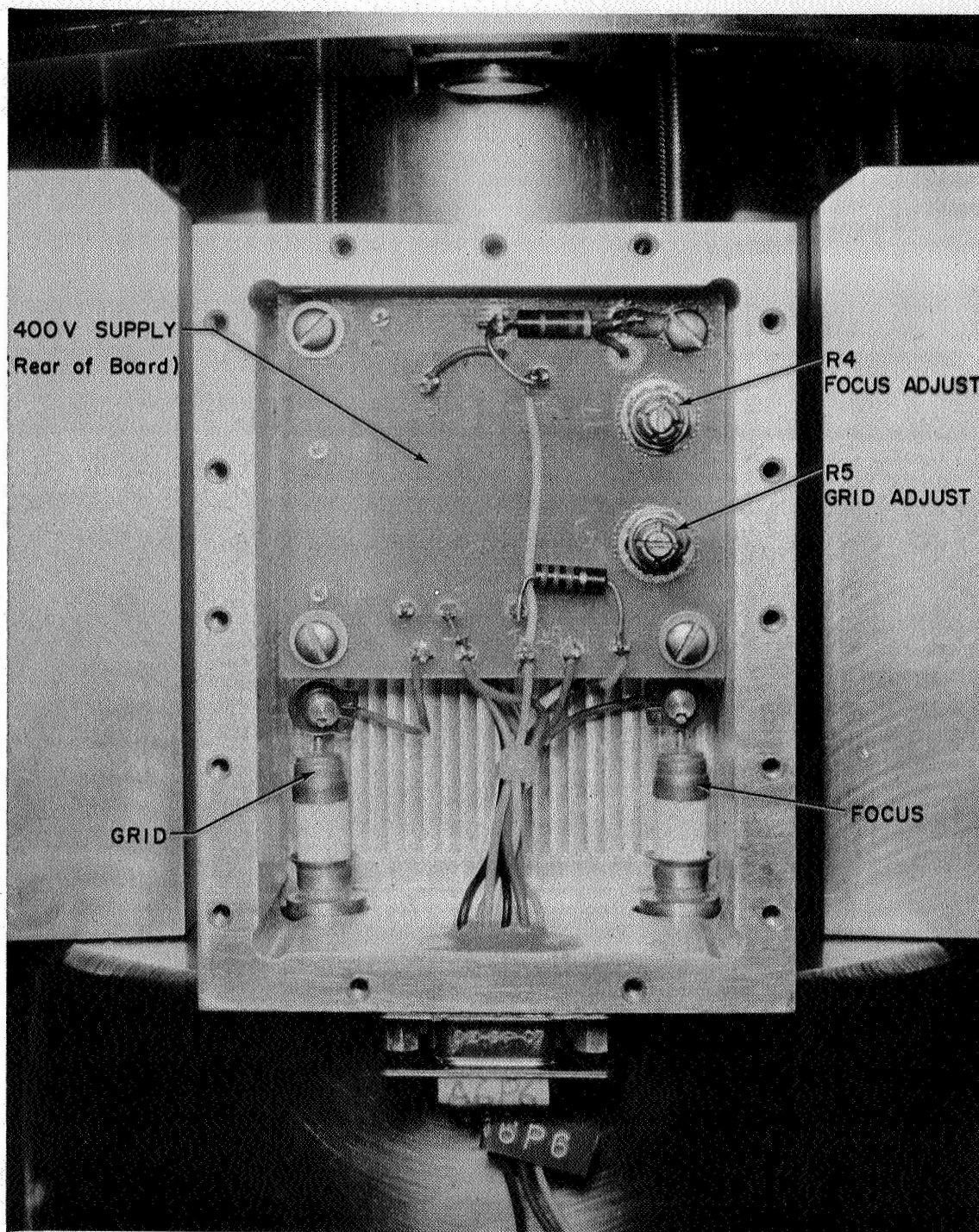
Figure 9. HV enclosure A3.

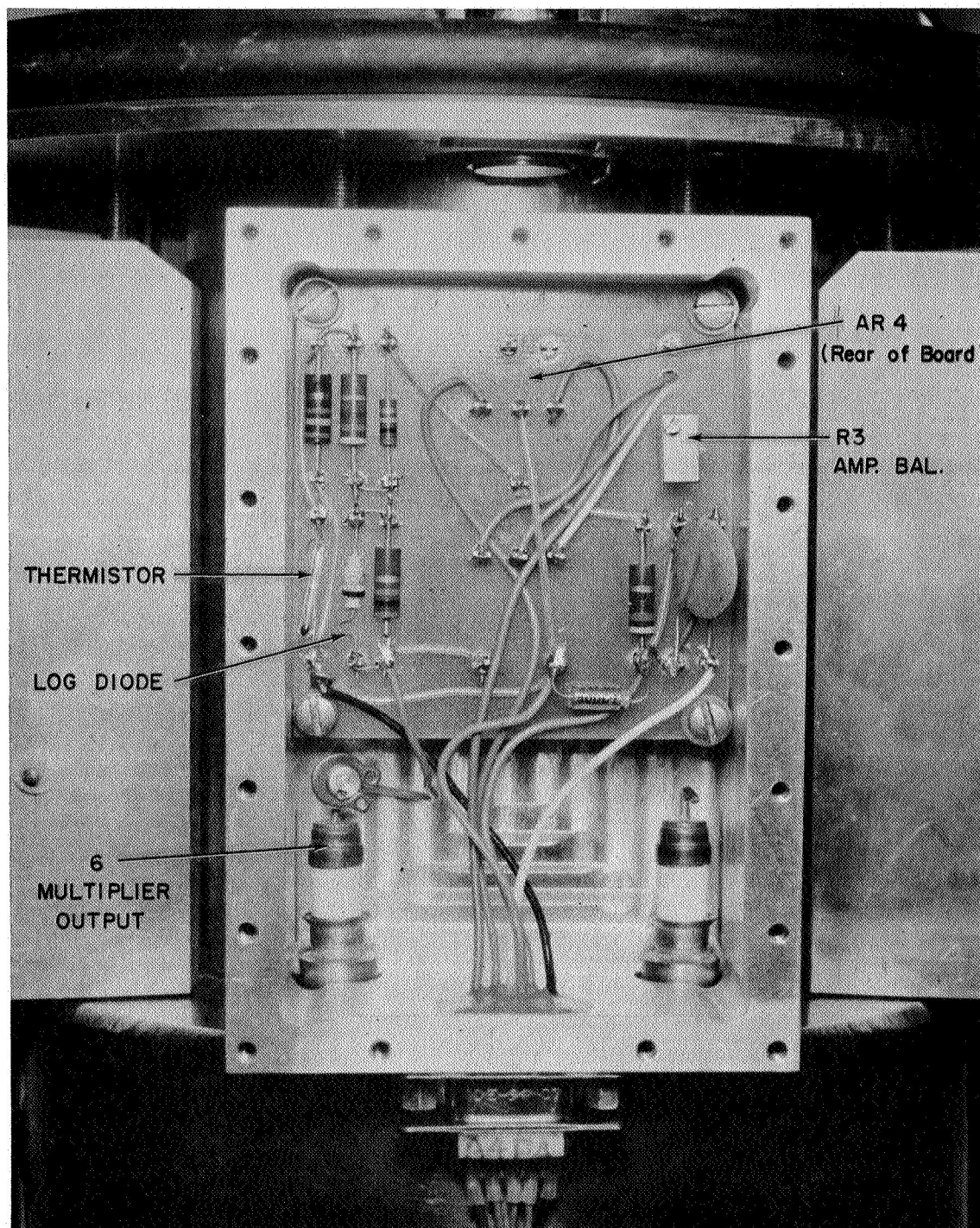Figure 10. Grid and focus supply A6.

Figure 11.   Electrometer A4.

A positive pulse is superimposed on the electrometer output to mark the start of each scan cycle. A second pulse of negative polarity is provided to mark the start of the extended mass range scan. Both pulses are obtained by capacitive coupling from the relay coil voltage.

3.6 Low Voltage Supply (See Figure 12)

Two Technipower CMP-15 regulator modules are used to supply the plus and minus 15 volts needed for the operational amplifiers. These voltages are derived from the ±28 volts primary input power. These modules are mounted on one of the 6-inch circular boards. On this same board is the potentiometer for the adjustment of the high voltage for the electron multiplier and a control relay which can be used to turn off the high voltage supply.

There is also the telemetry subcarrier oscillator (Vector model MMO-11) for the IRIG band 21 with the center frequency 165 kilocycles and an intelligence bandwidth of 2475 cycles at a modulation index of five.
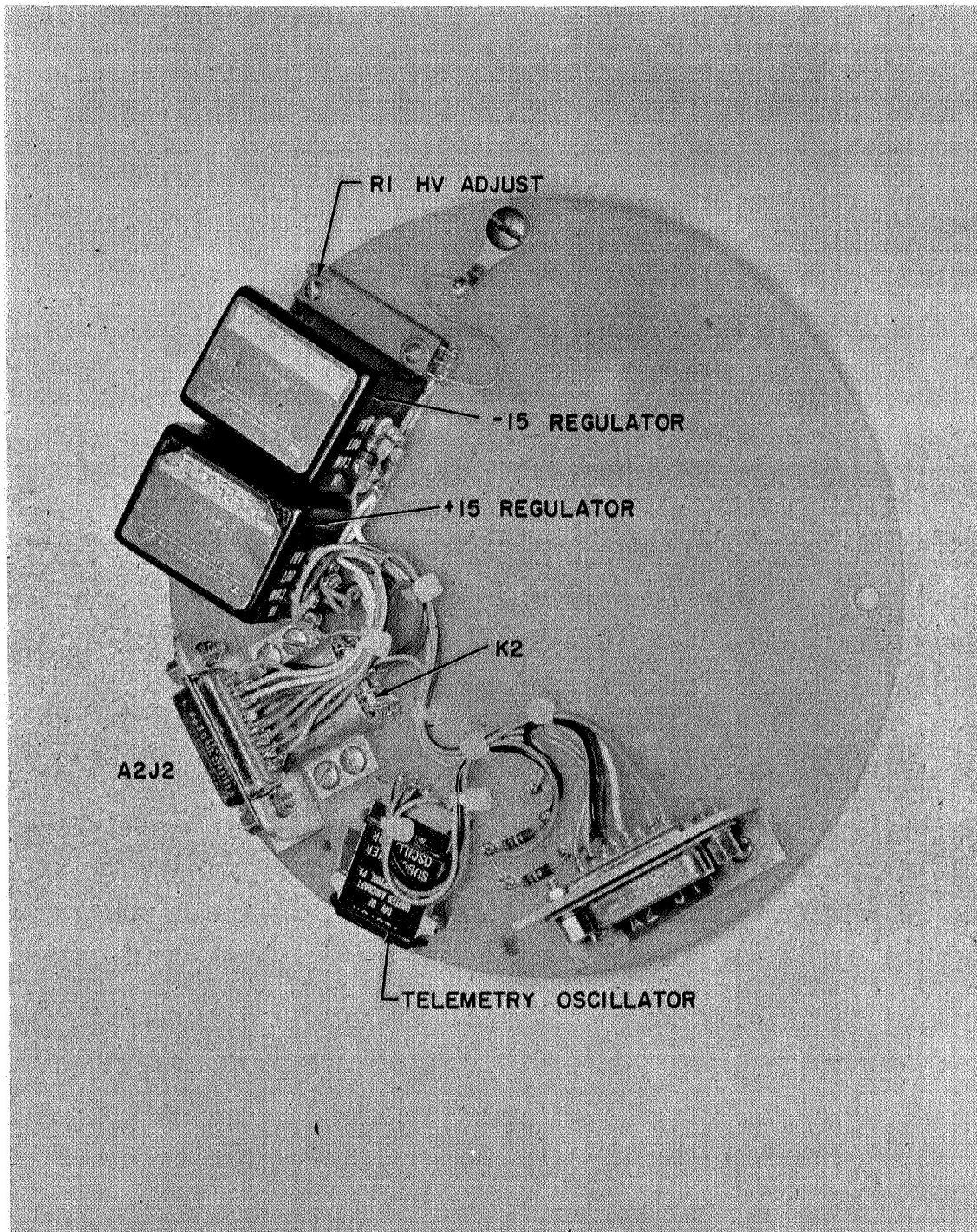
Figure 12. Low voltage supply board A2.

4. OPERATION INSTRUCTIONS FOR THE INSTRUMENT IN THE LABORATORY

4.1 Pump-Down Procedure

The pump-down procedure is quite simple if the instrument was already in operation and had not been exposed to air at high pressure. A much more complicated and time consuming procedure is necessary if the instrument was open and especially if the filaments or the anode have been replaced.

If the electrostatic ion pump was in operation for some time an active titanium layer has been deposited on the wall of the pump. This layer is adequate to keep the pressure in the system well below the 10^{-7} range, even after storage of the instrument for about a month. The gas which is released consists mainly of argon and can be pumped away within a few seconds after the pump has been switched on. It is also necessary to switch on the pump if, during the testing, a large amount of gas was introduced into the instrument and the pressure went up into the micron range. Before the pump is switched on, the pressure must be checked. If the pressure is higher than about 10 microns (measured with the thermocouple gauge attached to the ion source), it is advisable to connect the instrument to a diffusion pump system. If the pressure is lower, the built-in electrostatic ion pump will easily handle the load. The ionization gauge can be switched on if the pressure is lower than about a micron. The necessary connections have been described in Section 2.5. The electrostatic ion pump should be operated with a standard power supply for an NRC Orb Ion Pump since this power supply contains an emission regulator. The following connections have to be made: The center pin of the NRC power supply cable has to be connected with the high voltage cable to the anode of the electrostatic ion pump. Pin No. 6 has to be connected to the pump housing. Pin No. 3 to the filament common, which is the center feedthrough. Pin No. 2 to the other end of either one of the two filaments which is one of the two other feedthroughs. Pin No. 1 has to be connected with pin No. 5 in order to activate the high voltage power supply. A blower has to be placed beside the instrument to blow air into the large hole in the shell through which the filament feedthroughs are visible. This provides adequate cooling for the pump. The power supply is adjusted as follows: bias maximum, emission maximum, filament on, filament parallel, high voltage zero. Then the main power and also the high voltage can be switched on and slowly raised until the first sign of an emission current occurs. This will happen at approximately 4000 volts. Observation of the ionization gauge indicates that no outgassing occurs and the pressure drops down rapidly. Pumping a few seconds with only about 5 milliamperes is sufficient to reduce the pressure from 10^{-4} to 10^{-6} torr. However, if getter pumping with the switched off pump is intended, it is necessary to operate the pump at normal power for a few hours. For this purpose, the high voltage is raised gradually until an emission current of approximately 20 milliamperes is obtained. If this occurs at a voltage smaller than 11 kilovolts, the emission control setting has to be reduced which permits an increase of the high voltage. Maximum operating conditions

for this small pump are 11 kilovolts and 20 milliamperes. Full power operation is seldom necessary. About 10 kilovolts and 15 milliamperes are sufficient for routine operation; this results in an extended pump lifetime.

If the interior of the instrument was exposed to air at atmospheric pressure the pump-down procedure is more time consuming. First the instrument has to be evacuated with a diffusion pump system. For this purpose, it is convenient to use a standard Veeco leak detector which permits quick elimination of any leak which might occur at the ultra-high vacuum flange if the bolts have been insufficiently tightened. Due to the small diameter (1/2 inch) of the roughing-out valve, it will take a few hours to bring the pressure down below the micron range. In this pressure range, a moderate bakeout of the system can be started. This can easily be done with a heating tape, if the instrument is removed from the external shell and mounted on the temporary support stand. Only the pump section below the center flange has to be baked. Slowly increase the temperature during an 8-hour period to a final temperature of about 300°C. This procedure prevents excessive heat in the upper part of the instrument that would necessitate removal of the electronic packages. High temperature bakeout of the whole instrument (less the electronic packages) is not necessary for the intended application. A small amount of background gases does not interfere with the detection of ambient ions. Only the pump walls have to be well outgassed to improve the adhesion of the titanium layer.

Start the outgassing of the pump filaments as soon as a pressure of approximately 10^{-5} torr has been reached. This should be done during the period when the pump housing is still hot. A very large amount of gas is released if new filaments have been installed. The filament current shall be increased gradually over a period of several hours up to a maximum value of approximately 5 amperes. New thoriated tungsten filaments have to be conditioned to produce enough emission current. Since the NRC power supply does not provide sufficient current for this conditioning process, a separate transformer has to be used; it should supply a maximum of 6.5 volts and 6 amperes, regulated by a Variac. A 300-volt battery with a milliampere meter is connected between the filament and the anode or between the filament and the housing. The filament current is increased very slowly until a small emission of approximately 1 milliampere appears. This small electron current releases a large amount of gas from the anode and a rapid pressure rise is observed. It may be necessary to interrupt the outgassing several times to keep the pressure below 10^{-4} torr. After several hours it is possible to increase the emission current to approximately 10 milliamperes with 300-volt anode potential and with the pump housing still hot. Thereafter, the filament current can be reduced to approximately 4 amperes and an emission current of 10 milliamperes can still be maintained. The same procedure is performed with the second filament. Thereafter, the heating tape is disconnected and the instrument is allowed to slowly cool down. After room temperature has been reached the heating tape can be removed. Now the electrostatic ion pump can be connected to the NRC power supply in the way

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described above. The blower has to be started and the voltage should be slowly increased. In contrast to the pump-down procedure for the well outgassed system, there will be a large amount of gas released during the initial operation of the pump. Titanium getter pumping can not be effective before titanium starts to evaporate, which requires approximately 10 kilovolts and 15 milliamperes. Before this amount of power can be supplied to the pump, the electron bombardment releases large amounts of gas. Every small increase in the supplied power increases the pressure and requires a considerable time to recover. Suddenly, evaporation of titanium will start and at this moment the pressure drops down rapidly. If this point has been reached the outgassing period has been terminated and shortly thereafter the roughing valve to the diffusion pump can be closed. The pressure will drop continuously and will be soon below the detection limit of the ionization gauge. Nevertheless, it is recommended that the pump be operated over night at 11 kilovolts and 20 milliamperes to produce a sufficiently heavy titanium layer on the wall which is required for the following experiments with the mass spectrometer.

Depending on the extent of the exposure to air, the type of cleaning, and the installment of new filaments or a new anode, it may take between two to five days until this point can be reached. Thereafter, maintenance of a good vacuum provides no difficulties and is much safer than any diffusion pump system because power failure does not deteriorate the vacuum.

4.2 Starting of the Ion Source

The rhenium filament of the source does not require conditioning in order to obtain good emission. However, outgassing will occur with any new filament. Since the ion chamber is evacuated only through the pinhole towards the mass spectrometer, it is necessary to raise the temperature of the filament quite gradually in order to avoid excessive pressure in the ionization chamber. Emission starts if an anode voltage of +22 to 45 volts is applied with a filament current between 3.8 and 4.3 amperes, depending on the pressure in the ion source. A higher pressure cools the filament and requires a higher filament current. The filament current should be adjusted to maintain an electron emission current of about 25 microamperes. The ion current depends on the polarity of the filament current. Therefore, ac current should not be used to heat this filament because it would introduce a 60-cycle modulation into the output signal.

4.3 Peak Monitoring and Slow Scan Mass Spectra

This mode of operation is important for the adjustment of the instrument in the laboratory. It allows the mass spectrometer to remain on a peak and enables the adjustment of the ion lens voltages for maxima output current. For this purpose, a specially wired test plug has been provided. This plug, inserted in the test connector A1J2, inactivates the automatic scanning and permits the connection to an external programmer, Kepco model NP 1-3000. The yellow wire of the plug has to be connected to terminal 15, the violet wire to terminal 16 and the red wire to terminal 17 of the

programmer. An x-y recorder (Moseley model 2DR-2) has been used to record the spectra. The voltage between the terminals 16 and 17 of the Kepco programmer has been connected to the x-axis of the recorder on the 1 volt/inch range. The y-axis has to be connected to the electrometer output pin 8 and the ground pin 4 on plug A2. The sensitivity in the y direction has to be adjusted to 0.5 volts/inch. There are two 28-volt dc power supplies necessary to operate the instrument. They should be isolated from ground and connected together into series. The white wire has to be connected to -28 volts, the brown wire to common and the blue wire to +28 volts.

If the pressure in the system is below 10^{-4} torr, the 28-volt power supplies can be switched on. Normal scanning speed is 10 seconds per turn or 100 seconds for the entire low mass range. Typical spectra are shown in Section 5.1. The electrostatic ion pump has to be switched off if a low background noise is required. With the manual control on the programmer, it is possible to adjust the instrument to any particular mass peak. This is necessary if the time dependence of the partial pressure of one particular gas has to be investigated or when the voltages for the ion lens have to be adjusted. Fortunately, the adjustments of the potentials for the grid and focus electrode are not critical. Potentiometers have been provided for this adjustment which are located in the box above the feedthrough connectors No. 1 and No. 2. It is not expected that readjustment will be necessary.

4.4 Introduction of Gas

The shutoff valve which is attached to the ion source has to be perfectly tight to permit a long shelf life of the instrument. This valve is not suitable for fine regulation of the gas flow into the ion source from atmospheric pressure. Therefore, an intermediate stage is necessary. This intermediate pressure of 10 to 100 microns can be provided simply by introducing gas through a needle valve to a fore pump. The shutoff valve provides sufficient regulation of the gas flow from this intermediate pressure into the ionization chamber. This valve must be opened very slowly by observing the electron emission current to the anode of the ion source. This current will decrease as soon as the gas flow starts. Introduction of different gases is necessary for the calibration of the mass ranges. It is advisable to perform the first such experiments with the electrostatic ion pump running, inspite of the additional noise introduced by it. The pump will quickly remove any excess gas which might be accidentally introduced into the system. Special care is necessary if gas is introduced into the system when the pump is switched off. The pressure should be monitored with the ionization gauge and an increase above a micron should be avoided. Excessive pressure in the system will result in a glow discharge in the multiplier which may damage the dynodes or the power supply.

4.5 Fast Scan Mass Spectra

Automatic mass scan has been provided for normal operation of the instrument during the rocket flight. One complete mass scan requires 2.1 seconds and consists of two parts. The regular scan with linear mass scale from mass 1 to 54 requires 1.4 seconds and the extended mass range from mass 54 to infinity requires 0.7 seconds. A recording system with a frequency response of at least 500 cycles per second is needed for the testing of the instrument in the laboratory.

Visual inspection of the spectra can be done conveniently with an oscilloscope. The previously used cable with the test plug has to be removed from the test connector A1J2 for the oscilloscope operation. Another test plug with cable has been provided to supply the synchronizing trigger pulse for the oscilloscope. This cable has to be connected to the external trigger terminal of the oscilloscope and to ground. The instrument output has to be connected to the oscilloscope amplifier input. The accurate adjustment of the oscilloscope depends on the model which is used. Therefore the following adjustments can only serve as guidelines. They have been obtained with a Tektronix oscilloscope model 545A.

   (1) Trigger: external, positive slope
   (2)   mode ac
   (3) Horizontal display A, magnifier off
   (4) Sweep time 0.1 second per centimeter
   (5) Connect the oscilloscope amplifier (Type H, plug in unit) to
the RF test point. Adjust the trigger stability and sweep speed to obtain a proper RF cycle display. Level adjustment in center position.
   (6) Switch the oscilloscope input to the electrometer output (yellow coax cable) and observe the spectrum.

With most oscilloscopes, it is possible to expand the mass scale or to display a part of the spectrum on an enlarged scale.

A Visicorder (Minneapolis Honeywell Corp.) is recommended if permanent recordings are needed. Preliminary results have been obtained with a hot stylus Sanborn Recorder Model 150. However, the response of this recorder is insufficient to reproduce undistorted spectra. The Visicorder amplifier gain should be adjusted to obtain full-scale deflection for 5-volt input. A higher gain can be used if the largest peak does not require the full range of the logarithmic electrometer. This has been done in Figure 22 where the intensity scale has been individually calibrated by supplying small currents to the electrometer amplifier. The normal paper speed is 10 inches per second. Four inches per second can be used to save paper but some details of the spectra are lost. The recorded spectra have to be protected from light or must be permanized with a special developer and fixer. A small positive pulse has been provided to mark the start of the regular scan and a negative pulse to mark the start of the extended range scan. Since a trigger pulse is not necessary, the cable, which has been provided for the oscilloscope operation can be removed.

5. DISASSEMBLY AND REASSEMBLY OF THE INSTRUMENT

Disassembly may become necessary during laboratory testing if the filaments of the ion source or of the ion pump have burned out or if the whole system has been badly contaminated.

5.1 Replacement of the Ion Source Filament

In this case the instrument shall be vented with dry nitrogen through the quarter inch valve on the ion source. This will considerably reduce the time required for pump down. The ion source can be removed after the instrument has reached atmospheric pressure. This is done in the following way. The two screws (45) have to be loosened and the plates (46) have to be turned to the side. This will permit to remove the springs (50). The two blocks (3) can now be turned with the aid of a screwdriver. This will release the two bolts and the cover will come off. The knob and nut on the 1/4-inch valve has to be removed and the high vacuum flanges can be unbolted from the main cover plate (5). Now, the two flanges can be disassembled for cleaning of the ionization chamber and for installation of a new filament. The filament has to be centered carefully. A new copper gasket has to be installed and the bolts have to be tightened equally to 15 lb-ft. The ion source with the valve can now be attached to the cover plate (5). The release bolts shall be returned in the locked position. For this purpose the piston has to be pushed upwards and the block (3) has to be turned back. The four bolts which connect the two plates (6) with the main cover (5) have to be loosened all the way. A new gold V-ring has to be installed. Extreme care is necessary during the installation of this delicate ring. It should be carefully centered around the sampling aperture (54) before the ion source is slipped over the extension of the housing. After the ion source is in place, new balls can be installed in the release bolts. One helper shall hold the washer (11) towards the flange (10). Now the four balls can be inserted from one side whereby the extension (14) prevents them from falling out on the other side. After the fourth ball is in the hole the washer (11) can be lowered. The same procedure has to be performed on the second bolt. The four screws which hold the plates (6) to the cover (5) have to be tightened evenly by carefully watching the gap between the ion source and the spectrometer housing. This gap shall have the same width all around and shall almost disappear. Finally, the springs (50) can be reinserted and locked into position with the plates (46) and the screws (45). The four explosive actuators shall not be installed before the bakeout of the instrument.

5.2 Disassembly of the Electrostatic Ion Pump

In this case the instrument can be vented with laboratory air. The support tube (36) has to be removed and the instrument placed on the four posts of the laboratory stand. The bolts of the 8-inch ultra-high vacuum flange can be removed and the mass spectrometer section can be lifted off. The copper gasket (26) and the grid (27) can be removed. The delicate

edge of the ultra-high vacuum flanges shall be protected with masking tape. The Truarc ring (28) and the small Truarc rings for the filament connections can be removed with the special tools supplied for this purpose. The three bolts (67) should be loosened by approximately one turn. Then the Truarc ring (68) can be removed with the special tool. Now the whole inner structure of the pump can be pulled out. The further disassembly depends on the repairs which have to be performed. It is recommended to remove the studs (30) and pull the whole lower cage away from the upper plate. This exposes the filament and anode for easy replacement. It is usually necessary to clean the wall of the pump housing since an excess deposit of titanium may peel off. This cleaning is best done with a stiff wire brush which leaves the surface rather rough and improves the adhesion of titanium. The insulators and ceramic bushings should be carefully inspected and cleaned if deposits of titanium are visible. Usually it will be necessary to install a new anode. During operation of the pump, the tungsten rod becomes so brittle that the anode will not survive the disassembly and assembly procedure. The assembly proceeds in the opposite sequence as the disassembly. The three bolts (67) have to be tightened moderately to remove the end-play between the triangular plate (69) and the Truarc ring (68).

5.3 Disassembly and Reassembly of the Mass Spectrometer

Under normal operating conditions, it is not expected that this should be necessary, however a brief description will be given below. The five Truarc rings (65) for connections to the feedthroughs have to be removed. The shield (25) and the two Truarc rings (22) have to be removed. There are two Allen head screws in the support ring (49). These screws have to be loosened half a turn with a special Allen wrench with extended shaft. Now the Truarc ring (62) can be pulled out of the housing. If further disassembly should be necessary, the connections to the electron multiplier have to be cut. After loosening the four nuts (24), all components can be slipped off the four rods (18). The assembly of the instrument proceeds in the reverse sequence. The multiplier connections have to be spot welded. The two Allen head screws in the ring (49) have to be moderately tightened to remove the end-play between the ring (61) and the Truarc ring (62). Some skill is necessary to make the connections (22) which are not easily accessible. No other difficulties are expected.

6. PERFORMANCE TESTS

The flight prototype instrument has been thoroughly tested for a period of approximately half a year, partly before and partly after the vibration tests. The results of these tests are summarized below.

6.1 Ion Source

Although the ion source is not part of a mass spectrometer for the measurement of ambient ions, it is necessary to test the performance of the instrument. Some knowledge of the ion output of the source is required to evaluate the overall sensitivity of the mass analyzer. For this purpose, the ion source has been attached to a separate test setup with the same entrance aperture as used in the flight prototype. Behind this entrance aperture was a Faraday cage which measured the total ion current by means of a Cary vibrating reed electrometer. The anode voltage was kept constant at 22.5 volt. A small amount of air was introduced into the ionization chamber and the pressure was measured with the thermocouple gauge. The electron current has been varied between 3 and 20 microamperes. The ion current emerging from the entrance aperture was proportional to this electron current. The ratio ion-to-electron current has a practically constant value of 5×10^{-8} independent of the pressure in the ion source if this pressure was between 2 and 20 microns. At a pressure below 2 microns the ion current decreased proportionally to the pressure. Above 20 microns the ion current decreased rapidly and disappeared completely. Apparently, the mean free path of the electrons becomes too short and the electrons cannot gain the necessary ionization energy. The accuracy of this calibration was limited by the thermocouple gauge which is not very reliable around a few microns. Nevertheless, it permits a rough estimate of the ion output of the source. For an electron current of 3 microamperes, one obtains approximately 10^6 ions per second in the pressure range between 2 and 20 microns. At a pressure of 10^{-6} torr, one obtains approximately 500 ions per second. Useful spectra of the background gas have been obtained at pressures below 10^{-7} torr, the detection limit of the ionization gauge attached to the mass analyzer. This has demonstrated adequate sensitivity of the instrument.

During the first experiments, the ion source filament was heated by ac current. This method worked satisfactory as long as only slow speed scanning was used. However, the fast scan speed revealed a severe 60 cycles per second modulation of the output signal. A thorough investigation resulted in the following explanation. The ion current which is emitted from the source depends strongly on the direction of the current flow through the filament and on the end of the filament which has been grounded. Maximum ion current output is obtained if feedthrough No. 1 is on ground or more accurately on housing potential and feedthrough No. 2 on +3.8 volt. The helical filament coil has its largest distance from the anode at feedthrough No. 1 and the shortest distance at feedthrough No. 3. The difference in the output currents is quite significant, more than one order of

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magnitude. Modulation of the output signal has been eliminated by heating the source filament with dc current from a 12 volt car battery. For this purpose a simple control box (Figure 13) has been built and delivered with the instrument.

It should be mentioned that the maximum energy of the ions and electrons is the same in this simplified ion source. This is of no concern for the present application to test the analyzer. The ion energy must be kept relatively low, approximately 20 to 30 volts, in order to maintain good resolution. Since the electron energy has the same low value the mass spectra look different from those normally obtained with 70-volt electron energy. The atomic peaks O_{16}, N_{14} and H_1 are heavily suppressed if the electron energy is reduced as far. If a similar ion source should ever be used for more general gas analytical work it would be necessary to incorporate another electrode which would permit the use of the normal 70-volt electron energy and reduce the ion energy to about 20 to 30 volts. A weak longitudinal magnetic field should also be incorporated since it will significantly increase the ion output current.

6.2 Mass Analyzer

The mass analyzer consists of the ion lens, the monopole mass filter, and the electron multiplier type ion detector. The ion lens consists of two electrodes, a grid electrode which is kept at -250 volts against the housing, and a focus electrode which is kept at -162 volts against the housing. The adjustment of these voltages is not critical. The accelerating field between the conical hole in the housing behind the sampling orifice and the grid electrode has a strong focusing effect, even if the gas pressure before the sampling orifice is so high that collisions occur near the sampling aperture. The entrance and exit apertures of the monopole filter together with the V electrode are kept at -13.3 volts against the housing. This means that ambient ions which enter the sampling orifice with practically zero velocity will have an energy of 13.3 electron volts in the mass filter. An increase of this voltage will improve the sensitivity and reduce the resolution. If this voltage is changed, readjustment of the grid and focus potentials will be necessary. The present value of -13.3 volts has been chosen with more emphasis on resolution than on sensitivity.

The housing of the mass spectrometer is insulated from the rocket skin which allows the application of a voltage of approximately -10 volts to the instrument housing against the rocket skin. The resulting field is expected to improve the sampling efficiency for positive ions. However, because of the fairly high gas pressure in the D region a large number of ion-neutral collisions have to be expected, which will reduce the efficiency of biasing the mass spectrometer against the rocket skin.

The ions are accelerated between the monopole mass filter and the first dynode of the electron multiplier. The entrance aperture to the electron multiplier is kept at a higher potential (-2650 volts) than the
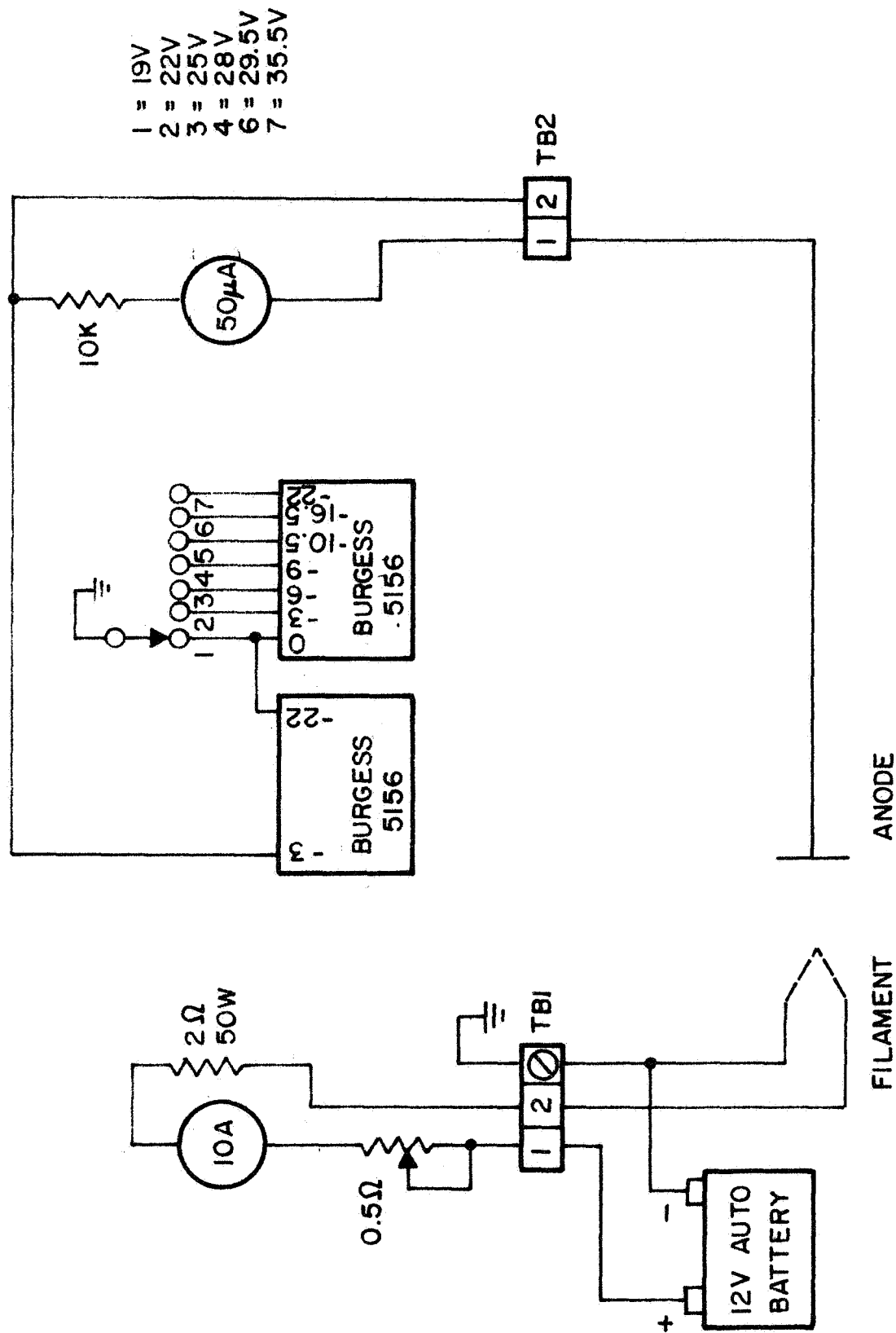
Figure 13. Control box for ion source of D-Region spectometer.

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first dynode (-2500 volts). This field between the entrance aperture and
the first dynode is necessary to prevent secondary electrons from the first
dynode from being pulled out through the entrance aperture of the electron
multiplier. A 16-stage electron multiplier (ITT Industrial Laboratories
Model No. F4020) with copper-beryllium dynodes has been used and worked
quite satisfactory. It's noise is negligible, even if the total voltage
is raised to 3500 volts, the maximum value allowed for this multiplier.
For the laboratory tests of the instrument, a smaller multiplier voltage
has been used ordinarily in order to improve the statistical accuracy of
intensity measurements of small peaks. For the actual flight experiment,
the sensitivity of the instrument can and should be increased about two
orders of magnitudes by increasing the voltage on the entrance aperture
to 3500 volts. In this case, each single ion will produce a visible peak
in the spectrum. The real limiting factor of the sensitivity is not the
multiplier gain but rather the small number of ions which contribute to
one mass peak. Due to the fast scan and the good resolution, about 300 ions/
second are necessary to insure the detection of most mass peaks, each con-
taining in the average about 3 ions. Since the gas flow through the samp-
ling aperture is about 10 cm^3/second, the theoretical detection limit is
30 ambient ions/cm^3, assuming about 100 percent transmission of the analyzer.
The only genuine way to improve the sensitivity is to increase the number
of ions which contribute to one peak. This can be done either by increas-
ing the sampling aperture or by increasing the scanning time. Both param-
eters are limited by practical considerations. The chosen values of these
and all other basic parameters are the result of a compromise between all
conflicting requirements.

6.2.1 Resolution of the mass analyzer.— The resolution of a monopole
mass spectrometer depends on geometric and electric parameters. The first
ones include the entrance and exit apertures, the rod diameter, and the
length of the filter. Based on the experience obtained previously with
the laboratory model, these parameters had to be chosen for the flight
model and cannot be changed any more. The electric parameters include the
dc to ac voltage ratio and the ion energy. A fixed ratio of dc to ac
voltage has been chosen for the regular mass range. Therefore the only
parameter left to adjust the desired resolution is the ion energy. The
Figures 14 through 16 show typical background spectra before the bakeout
of the instrument. The anode voltage used for these mass spectra has been
reduced from 52 to 30 and finally to 22.5 volts. The improved resolution
which has been achieved by reduction of the anode voltage is clearly visi-
ble, especially in the range between mass 12 and 18. The background of
this unbaked instrument includes mainly CO, CO_2, H_2O and the fragment ions
of these gases. The small peak of atomic hydrogen is clearly visible at
the beginning of the mass scale. Since the average energy of ambient
atmospheric ions passing through the sampling aperture is smaller than
the energy of ions from the ion source, it is expected that during flight
the resolution of the instrument will be better than the one obtained in
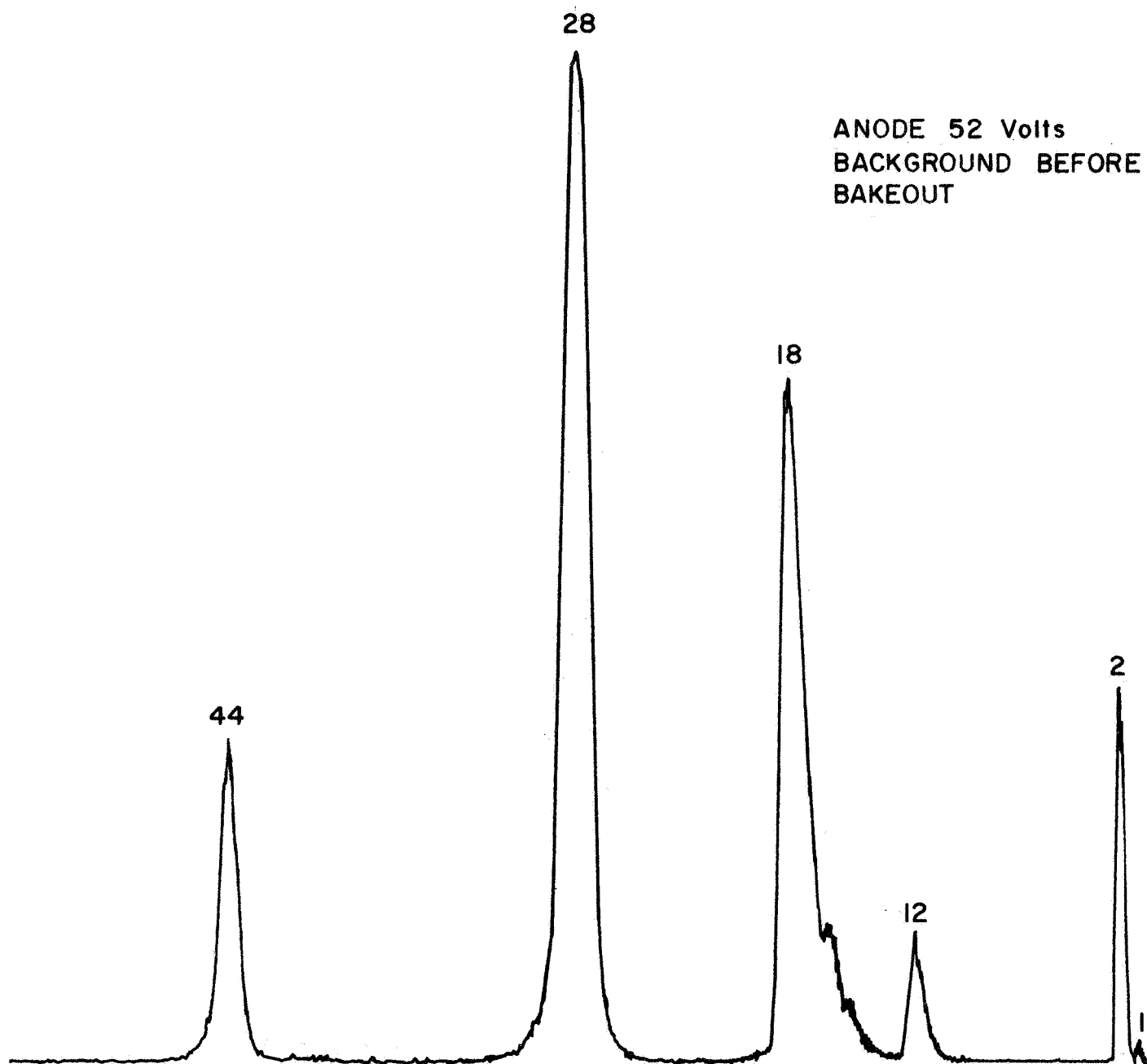Figure 16 and will be more than adequate to resolve single mass numbers
up to mass 55.

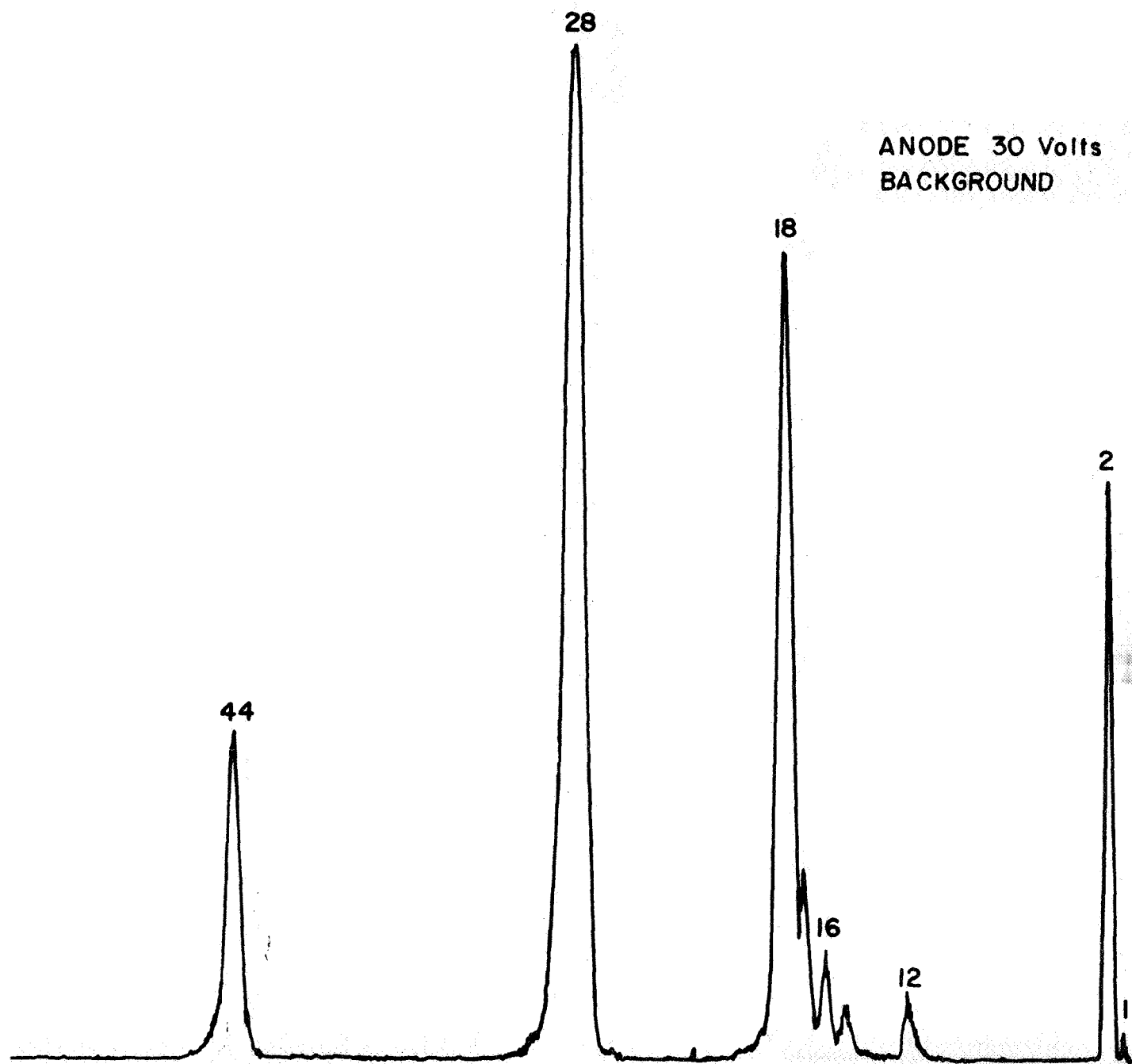Figure 14.   Background spectrum with 52 volts on anode.

Figure 15.   Background spectrum with 30 volts on anode.

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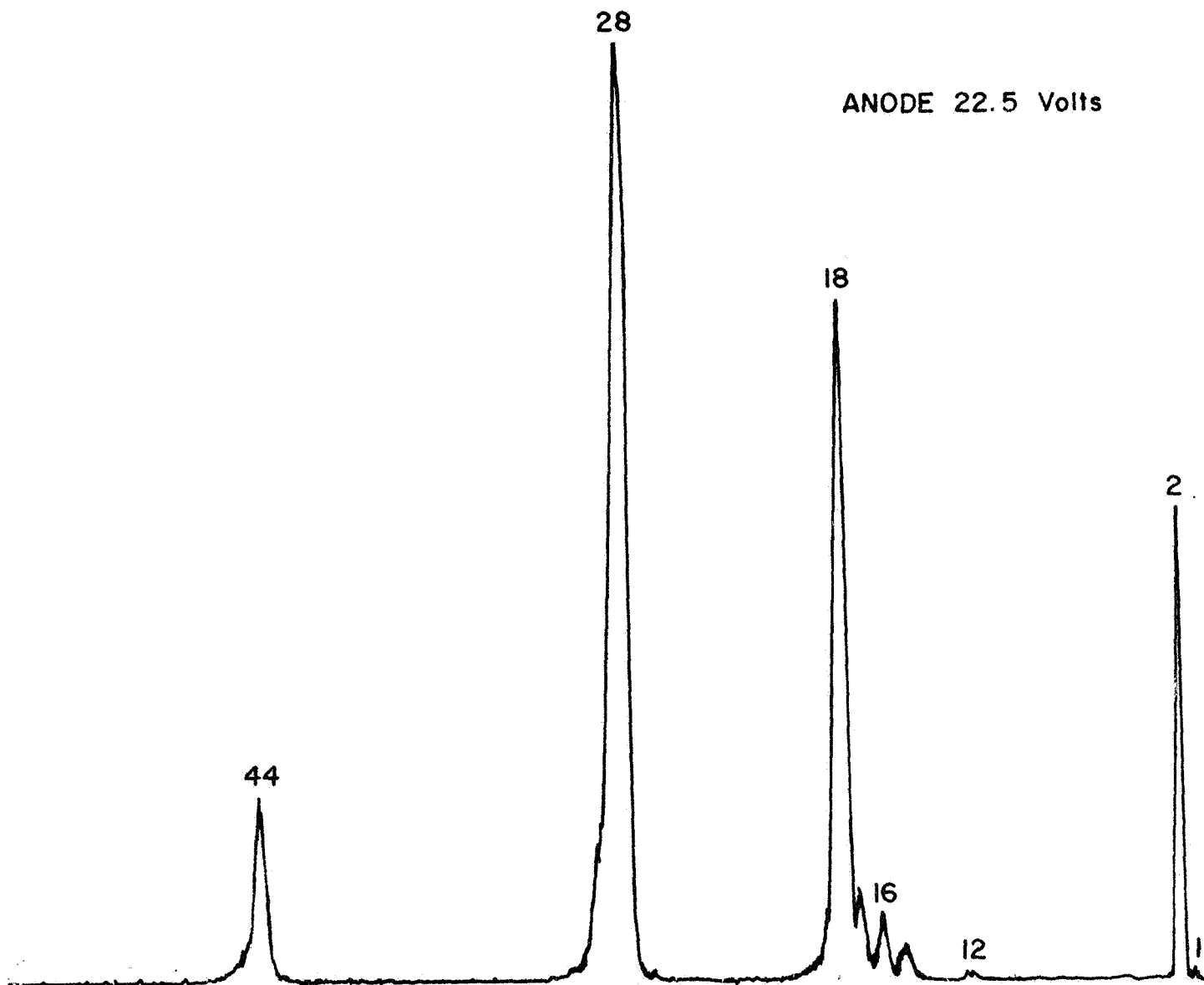ANODE 22.5 Volts

18

2

44

16

12

1

Figure 16.   Background spectrum with 22.5 volts on anode.

For the regular mass range of the flight prototype mass spectrometer a dc/ac (peak to peak) voltage ratio of 0.07 has been chosen which provides adequate resolution for ion energies up to 40 electron volts. This dc/ac voltage ratio is approximately 80 percent of the maximum value corresponding to the top of the stability diagram, which is the normal operating point for a quadropole mass spectrometer. Accordingly, the ac voltages are 80 percent and the dc voltages are 64 percent of the corresponding values for a quadropole instrument of the same size. Since only one instead of four rods has to be supplied with ac power, the basic ac power consumption of the monopole instrument is only 16 percent of the corresponding value for the quadropole instrument.

Figure 17 shows a mass spectrum of a mixture of helium and air which has been obtained earlier for the calibration of the low mass scale. Figure 18 is a regular mass spectrum of air after bakeout of the instrument. The smoother curve in the latter figure has been obtained by filtering the output of the electrometer preamplifier with a 0.47-microfarad capacitor. This capacitor has no detrimental effect for the fast mass scan and it simplifies the telemetry of the spectra. The relative peak heights of this air spectrum are different from the ones which are normally obtained from mass spectrometers using a Nier type ion source with 70 volt electron energy. Here, the electron energy is less than 30 volts which results in a suppression of the atomic species of oxygen and nitrogen. In addition, the getter action of titanium for argon it is practically zero and for water vapor is much smaller than for oxygen and nitrogen. If air is continuously introduced into the mass spectrometer ion source, the partial pressure of argon increases steadily, whereas the partial pressures for oxygen and nitrogen stay practically constant. These discriminatory effects have no adverse consequence for the intended use of the instrument to detect ambient ions in the upper atmosphere. The composition of the gas in the mass spectrometer has no effect on the mass spectrum which will be obtained from ambient ions, as long as the pressure in the instrument is below approximately 2×10^{-4} torr.

6.2.2 Sensitivity of the monopole mass spectrometer. — The sensitivity of the monopole mass spectrometer is a complicated function of all design parameters of the instrument. This has been thoroughly studied with the laboratory instrument and the results will be reported in detail in the first part of the final report. In the meantime, a short summary shall be given here. Higher sensitivity can be obtained with some sacrifice of resolution and vice versa. The sensitivity is generally improved with increasing ion energy. However, this function has several maxima and minima which occur at different ion energies for different masses. Therefore, the relative peak heights depend on the ion energy. This is the result of the limited number of oscillations of the beam in the monopole field. The effect has been minimized in the flight prototype instrument by use of wide entrance and exit apertures. Based on the experience with the laboratory instrument, it is expected that the sensitivity variations are less than 20 percent in the flight prototype instrument. They can be entirely eliminated by calibrating the instrument with the same ion energy as anticipated during the flight experiment.

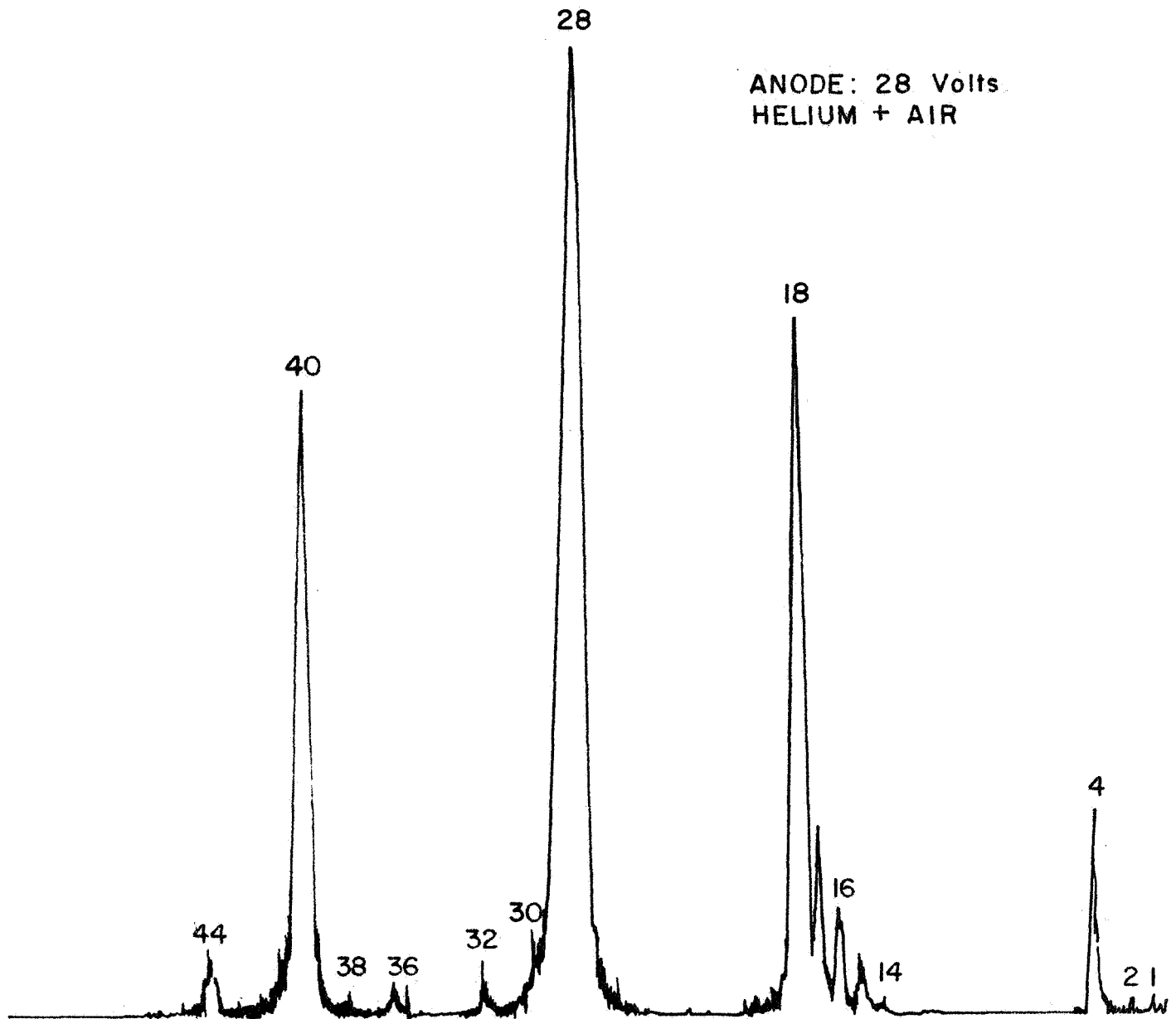Figure 17.   Air and heluim spectrum with 28 volts on anode.
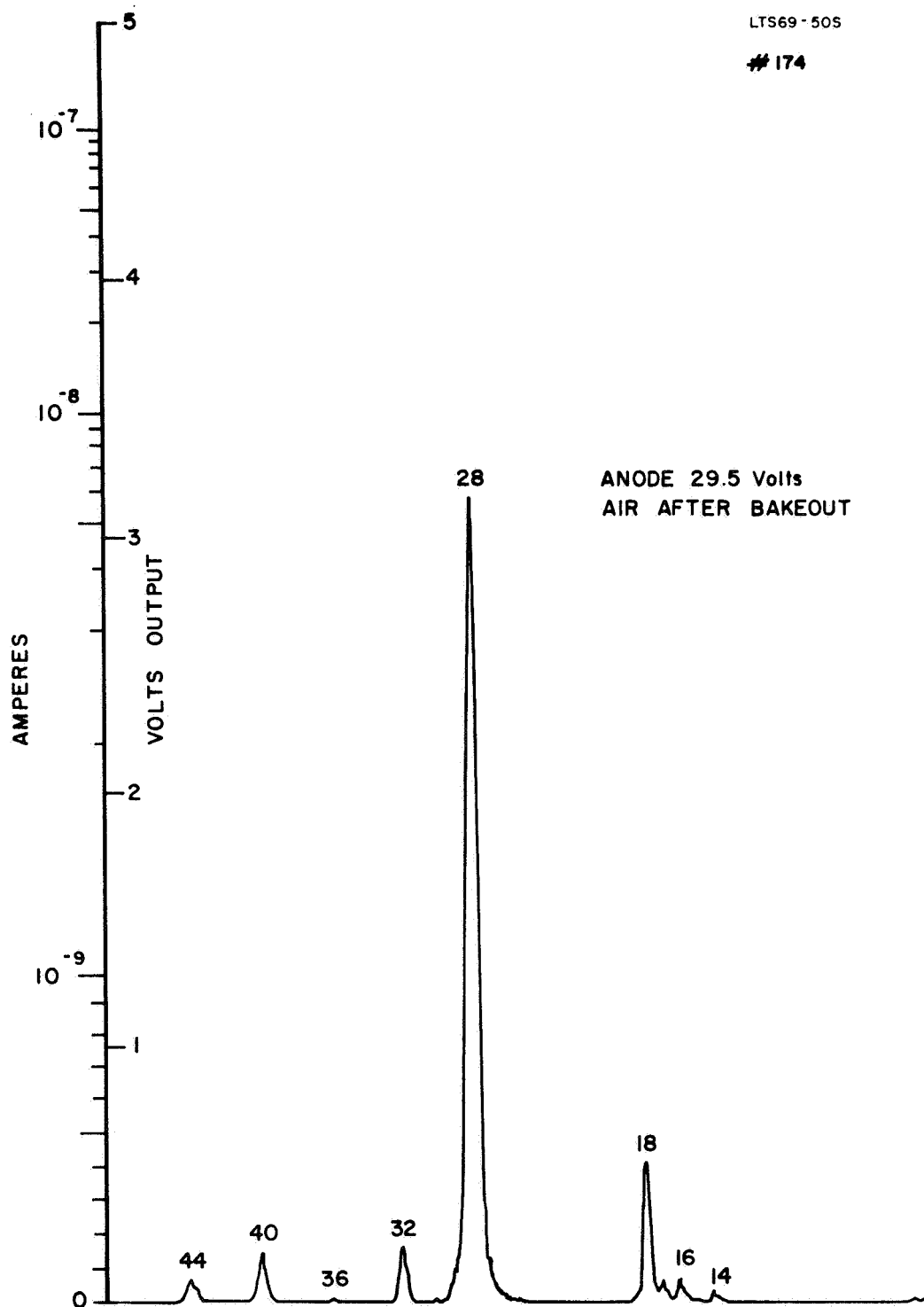
44

Figure 18. Air spectrum after bakeout.

An important figure for the evaluation of the instrument is the over-all transmission coefficient which shall be defined as the ratio between the number of ions leaving the monopole filter to the number of ions entering through the sampling aperture. Theoretically, it should be possible to measure both currents with Faraday cages, one right after the sampling orifice and the other one after the exit aperture. The first one must be retractable to permit the ion beam to pass through the filter. Practically, there is not enough space between the sampling orifice and first grid to permit the introduction of a Faraday cage. Therefore, an indirect method had to be used. The original gain of the electron multiplier, when obtained from the factory in a vacuum sealed housing, was 3×10^5 for a total voltage of 2500 volts. An accident during the pumpdown procedure has contaminated the multiplier with pump oil. The multiplier has been washed with trichloroethylene and was thereby exposed to normal laboratory air of moderate humidity for several weeks. The gain of the multiplier decreased about one order of magnitude. The ion output current can be calculated by dividing the multiplier output current with the multiplier gain. This ion current can be compared with the output current from the ion source which was measured independently as described in Section 6.1. Under these assumptions, one obtains an overall transmission coefficient of approximately 15 percent.

Experiments with the laboratory instrument have indicated that the sensitivity of the instrument can be increased by a factor of five if a weak magnetic field is generated near the entrance aperture of the monopole field. The direction of the magnetic field must be such that the beam is deflected towards the rod. If the field has the opposite direction the sensitivity is drastically reduced. A Nier type ion source was used in the laboratory instrument and the direction of the electron beam in this source was parallel to the direction of the magnetic field. The reversal of the direction of the magnetic field cannot have any effect on the ionizing electron beam. It must be concluded that the output current of the ion source was not affected by the magnetic field, but that the slight deflection of the ion beam towards the rod has improved the transmission of the analyzer. A similar effect has been observed with the flight prototype. However, here the effect is less unambiguous because the electron beam in this simplified ion source is in axial direction and will be strongly deflected by the magnetic field.

In the first version of the flight prototype the focus electrode has been split to permit electrostatic deflection of the beam before the monopole field. Surprisingly, no improvement of the sensitivity could be obtained. Therefore, in the final version of the flight prototype the split focus electrode has been replaced by a single focus electrode. The main difference between the electrostatic and the magnetic deflection of the beam is that the first one is localized to a very short region in front of the entrance aperture whereas the latter one is distributed over an appreciable length of the ion path and extends well into the monopole field. Apparently, this more gradual deflection is essential for the improvement of the transmission. Further investigations of this valuable effect are recommended especially if a higher sensitivity is needed.

6.2.3 Mass scale. — During the regular mass scan the mass scale is essentially linear. This can be seen from Figure 17 which represents a background and air spectrum with a small amount of helium added to the air to provide the peak at mass number four. A slight deviation of the linear mass scale occurred at the very low end for the masses one to four. This can be best seen on Figure 19 where the center part of the linear mass scale has been extrapolated all the way down to mass zero. The molecular hydrogen peak 2 is about at position 3 of this scale. This slight compression of the mass scale for very low masses is caused by the non-linearity of the rectifier diodes used for the production of the dc voltage which should be proportional to the ac voltage. This voltage ratio is no longer constant if the voltages are extremely small. The molecular hydrogen peak at mass 2 is usually present in the background spectrum and is a convenient marker for this part of the mass scale. The atomic hydrogen peak at mass 1 is much smaller and requires a higher anode voltage to be visible. A typical air spectrum after bakeout is shown in Figure 18. One can see that the water peak 18 is heavily reduced by the bakeout and that the hydrogen peak disappeared. The oxygen peak 32 is smaller and the argon peak 40 is larger than the related partial pressures of these gases in air. This is mainly the result of different absorption speeds on the titanium layer and of reactions with the source filament. The intensity scale in this figure shows the semilogarithmic relation between the instrument output voltage and the electron multiplier output current.

One valuable and unique feature of this instrument is the extended mass range which covers approximately mass 55 to mass 400 with decreasing resolution and increasing sensitivity. During this part of the mass scan, the ac voltage is kept constant and the dc voltage is reduced to zero, which can be done conveniently by discharging a capacitor. The purpose of this extended mass range is to detect any heavier ions which might be present in the upper atmosphere. The advantage of this compressed mass scale is that a wide mass range can be covered in the relatively short time of approximately 0.6 seconds. An extension of the linear mass range from mass 55 to mass 400 would require an additional scanning time of approximately 5 seconds which is much too long to obtain sufficient height resolution during a rocket experiment. Linear mass scale with faster scan would reduce the sensitivity and would produce sharper peaks which represent a serious difficulty for the telemetry of the spectra. In addition, the power requirements for a linear mass range monopole mass spectrometer would be approximately 50 times higher. The peak shape of the extended mass range is practically the same as for the regular mass range which considerably facilitates the telemetry. The resolution of the linear mass range is proportional to the mass and the resolution of the extended mass range is essentially constant, similar to the resolution of a magnetic type mass spectrometer. However, in contrast to a magnetic spectrometer with electrostatic scanning, the sensitivity of the monopole instrument is increased for heavier masses. This special feature of the flight prototype will allow obtaining valuable information about all heavier ions which are present in the upper atmosphere, together with a rough determination of their mass number. These additional results are obtained with very little sacrifice in height resolution and with only minor complications in the power supply for the instrument. The extended mass range is unique for the monopole mass spectrometer and cannot be achieved with a quadropole instrument.

Since the mass scale of the extended mass range is nonlinear, an accurate calibration is necessary. For this purpose materials have to be introduced into the ion source which have a large molecular weight and a well known spectrum. The characteristic mass peaks should be sufficiently wide apart to be separated even at the reduced resolution of the extended mass range.

The first material which has been used for this purpose was sulfurhexafluoride. The slow scan spectrum of this material with the linear mass range is shown in Figure 19. Most fragment ions, some of them multiple charged, have been observed. The spectrum shows some abnormalities which are due partly to the small anode voltage of only 22.5 volts and partly to the relatively high pressure in the ion source. The normal background spectrum before the introduction of SF_6 consisted mainly of the peaks at the masses 28, 44, 18, 17, 16, 2 and 1. The introduction of SF_6 produced a very large peak at mass 20 and simultaneously caused a considerable reduction of the peak at mass 2. No fluorine peak at mass 19 became visible. Apparently, due to the high pressure in the ion source, the fluorine has reacted with the hydrogen which is produced mainly by the decomposition of water vapor, and the 20 peak is caused by HF. A similar reaction can be observed with sulfur (main peak at mass 32) where the molecules HS (mass 33) and mainly H_2S (mass 34) have been found. At the heavy end of the mass scale the peaks from the molecular fragments SF_3 (mass 89) and SF_4 (mass 108) are characteristic milestones of the mass scale.

A fast scan mass spectrum of sulfurhexafluoride is shown in Figure 20. It consists of the linear portion of the spectrum up to mass number 54 and the extended mass range. By far the largest peak is caused by the fragment SF_5 at mass 127. The peaks at 108 and 89 are again clearly visible. From previous work with this material, it is well known that the molecule of the parent peak SF_6 at mass 146 does not form positive ions.

The start of the extended mass range, which is identical with the end of the regular mass range, is marked by a negative pulse. The end of the extended mass range, which is identical with the start of a new regular mass range, is marked by a positive pulse. These two markers are sufficient for the positioning of the mass scale and eliminate the need to telemeter the scanning voltages for the mass determination. Maximum gain of the Visicorder amplifier has been used for all fast scan spectra. The calibrated intensity scale is shown on the right side of Figure 20.

Since three points are not sufficient to calibrate the extended mass range, another calibration has been performed with perfluorodimethylcyclohexane C_8F_{16}. This material is a liquid but has a sufficiently high vapor pressure at room temperature to be introduced directly into the inlet system of the mass spectrometer. The mass spectrum of this material is relatively simple since it consists basically of two sets of lines which are either 12 or 19 mass numbers apart, depending on whether a carbon or fluorine atom has been removed from the molecule. Figure 21 shows a slow scan mass spectrum of this material and Figure 22 a fast scan mass spectrum.
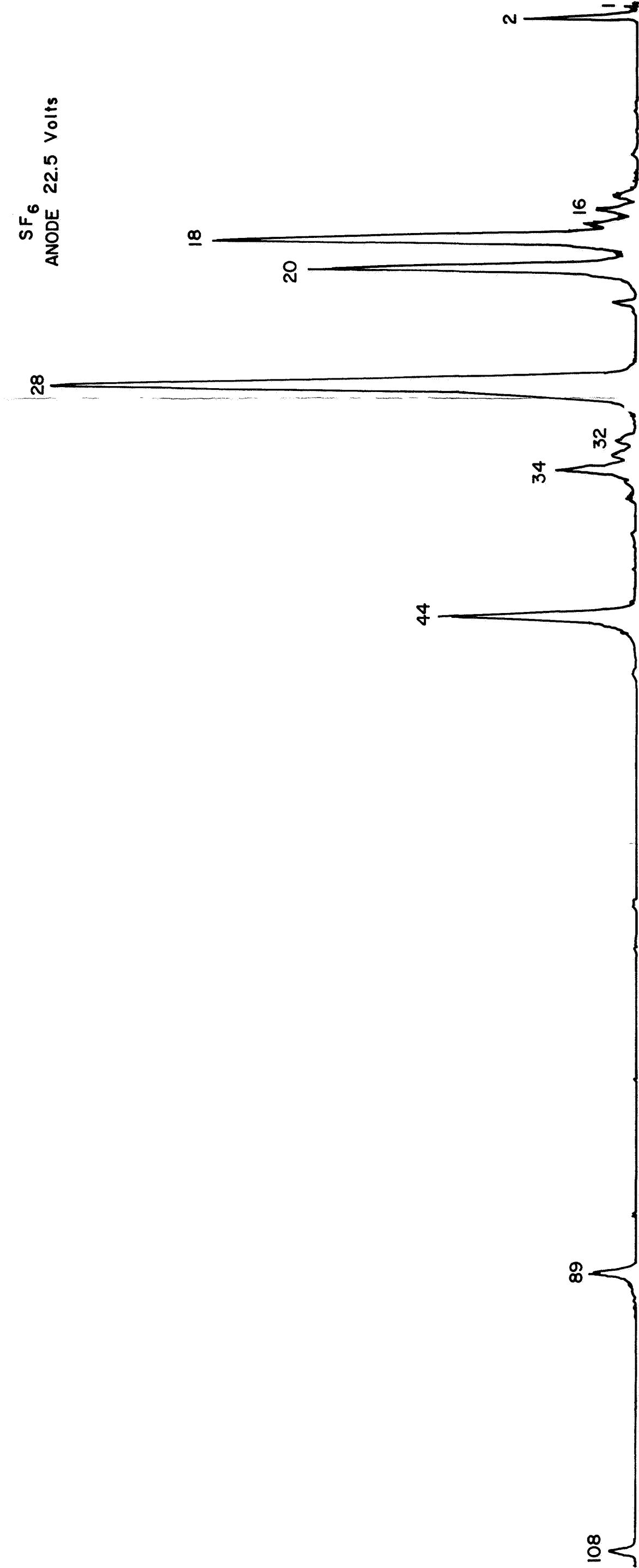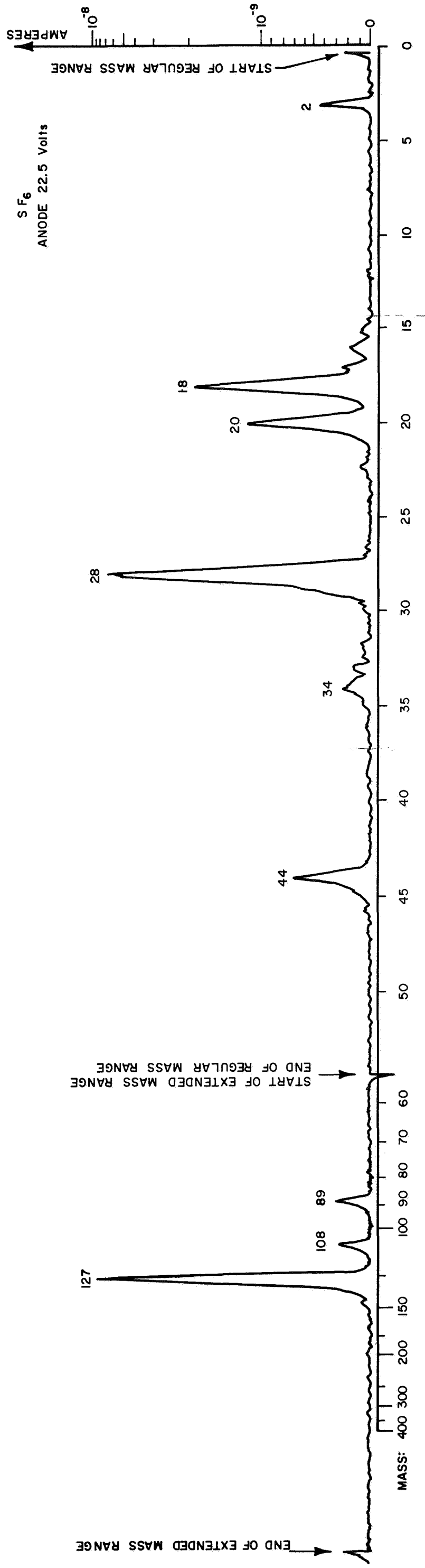
48

LTS69-60S

117

SF$_6$
ANODE 22.5 Volts

Figure 19. SF$_6$ spectrum, slow scan.

49

Figure 20. SF$_6$ spectrum, fast scan.

AMPERES

10^{-8}

10^{-9}

START OF REGULAR MASS RANGE

LTS69-130S
#116

SF$_6$
ANODE 22.5 Volts

2

18

20

28

34

44

89

108

127

END OF REGULAR MASS RANGE
START OF EXTENDED MASS RANGE

END OF EXTENDED MASS RANGE

MASS:

50

LTS69-70S
#118
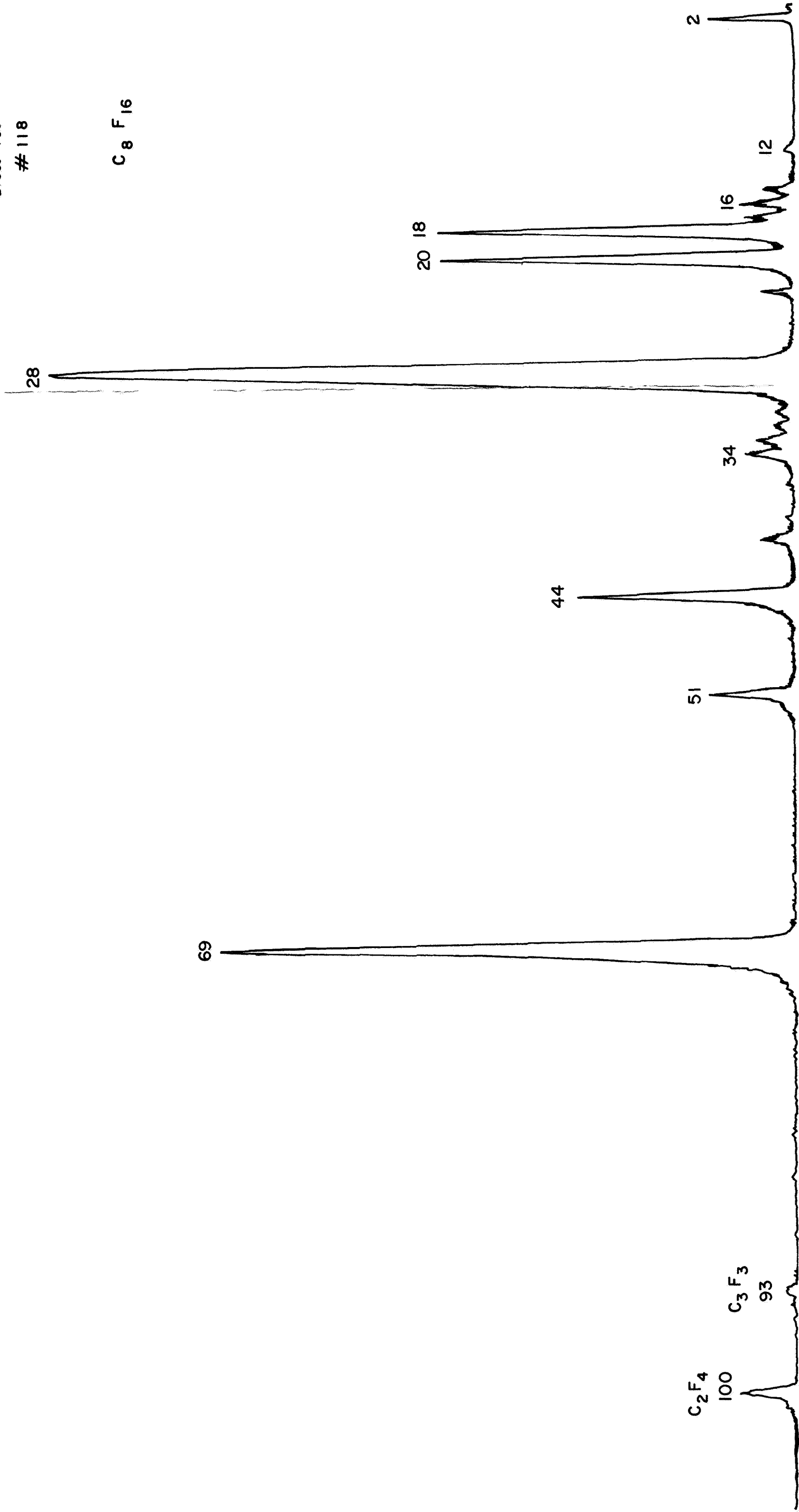
$C_8 F_{16}$

Figure 21. C_8F_{16} spectrum, slow scan.

51

MASS SPECTRUM OF C_8F_{16} 0.1 seconds/inch
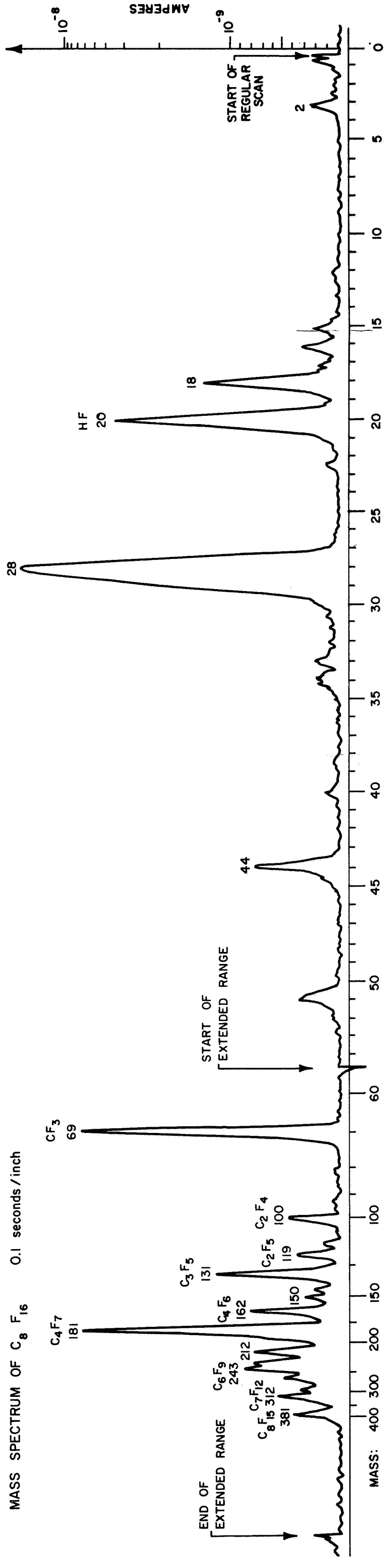
Figure 22. C_8F_{16} spectrum, fast scan.

52

The peaks have been identified by comparison with a mass spectrum obtained with a large magnetic mass spectrometer. The radicals which correspond to the major peaks are marked in the spectrum. The sensitivity of the monopole mass spectrometer increases for heavier masses in contrast to a magnetic type mass spectrometer, especially if the latter one is scanned with the acceleration voltage. It can be assumed that even larger masses will produce peaks. However, mass determination of very high masses is restricted due to the small resolution and large compression of the mass scale.

A third material which has been used for the calibration of the extended mass range is carbon tetrachloride $CC\ell_4$. The slow scan spectrum of this material is shown in Figure 23 and the fast scan spectrum in Figure 24. Unfortunately, this material has badly contaminated the instrument. The chlorine ions, which have been split off from the molecule by electron bombardment, reacted with the hydrogen background and produced hydrochloric acid which become the major contaminant of the background gas, long after the introduction of $CC\ell_4$ had been stopped and the instrument was pumped down again. This can be seen from Figure 25 which contains the two large peaks at mass 36 and 38. The size of these peaks could not be reduced either by extended pumping over several days or by venting the instrument to air at atmospheric pressure. They have been finally removed by exposure to NH_3 and by baking over several days.

These calibration experiments for the extended mass range have proven that this unique feature of the monopole mass spectrometer is extremely valuable to detect whether there are any masses present in the spectrum which are beyond the regular mass range. In addition, a rough mass determination is possible with the monopole mass spectrometer whereas a quadropole mass spectrometer can only provide an information about the sum of all heavier masses.

6.3 Pump Performance

6.3.1 Titanium getter pump. — The behavior of the titanium getter pump confirmed the results obtained previously from the laboratory instrument. The basic limitation of this pump comes from the fact that rare gases are not absorbed. Since argon is the most abundant rare gas in the atmosphere, it becomes the main constituent of the background gas after a large amount of air has been introduced into a system which is pumped only by a titanium getter. The pressure buildup can be easily calculated. The internal free volume of the flight prototype is approximately 5 liters. The maximum operating pressure of the instrument cannot be defined accurately. Mass spectra for qualitative investigations have been obtained at pressures as high as 5 microns. However, the sensitivity is severely reduced if the mean free path of the ions is shorter than the length of the monopole filter and in this case the partial pressure is an ambiguous function of the peak height. Since the sensitivity stays fairly constant up to a pressure approximately 2×10^{-4} torr, it is not recommended to exceed this pressure. This partial pressure of argon will exist in the

instrument after 10^{-3} torr liters of argon or approximately 10^{-1} torr liters of air have been introduced. The total pressure in the system will be slightly higher than the partial pressure of argon because also some of the other atmospheric gases, especially nitrogen, are not completely absorbed. Near saturation of the getter the partial pressures of nitrogen and argon are usually approximately equal. Absorption of nitrogen can be improved if the active titanium layer has been deposited at a high pump wall temperature under high vacuum conditions. This requires continuous pumping with an external pump to remove the large amount of hydrogen which is released during this process. The small fraction of atmospheric nitrogen (about 1 percent) which is not absorbed by the cold titanium getter will be absorbed quickly and completely by the same practically saturated getter if its temperature is increased to about $200^{\circ}C$. Higher temperatures should be avoided since titanium hydride starts to decompose and produce a large hydrogen background. It shall be mentioned that, in contrast to nitrogen, oxygen has been always completely absorbed.

The titanium getter worked extremely well to maintain high vacuum ($\sim 10^{-7}$ torr) in the instrument during a long storage period of about 3 months. Nevertheless it is recommended to operate the pump for about 1 hour shortly before launch of the rocket in order to produce a fresh layer of titanium with maximum absorption capability.

The altitude at which the instrument can be opened is approximately 75 kilometers. The accurate value can only be calculated after the total weight of the whole payload will be known. This weight determines the maximum altitude which can be reached by the tomahawk rocket. The velocity as a function of altitude must be known to permit the calculation of the gas flow through the entrance aperture.

Several experiments have been performed to study the speed of nitrogen absorption on the titanium getter. For this purpose a large amount of air has been suddenly introduced into the ion source and the height of the 28 peak has been monitored (see Figure 26). The inlet manifold was evacuated with a forepump and a pressure of 0.3 torr was adjusted with a needle valve. This pressure dropped to 0.18 torr when the 1/4-inch valve to the ion source was opened. This valve has been kept open for 5 seconds during which time 50 cm^3 of air could pass through the sampling orifice and another 60 cm^3 has filled the total volume of the ion source with the thermocouple gauge. This corresponds to a total gas flow of about 0.02 torr liter of air. The height of the 28 peak at the start of this experiment was caused by the amount of air which had been introduced during previous experiments. When the valve is opened, the 28 peak increases suddenly, as expected, and disappears almost completely for about 7 seconds. During this time, the pressure in the source is so high that practically no ions can be formed. As the pressure decreases, the mean free path of the electrons increases and ions are formed when the energy exceeds the ionization potential. Maximum ion current has been obtained after about 20 seconds. The absorption process is essentially completed after about 40 seconds. One can see that after this experiment the 28 peak is slightly
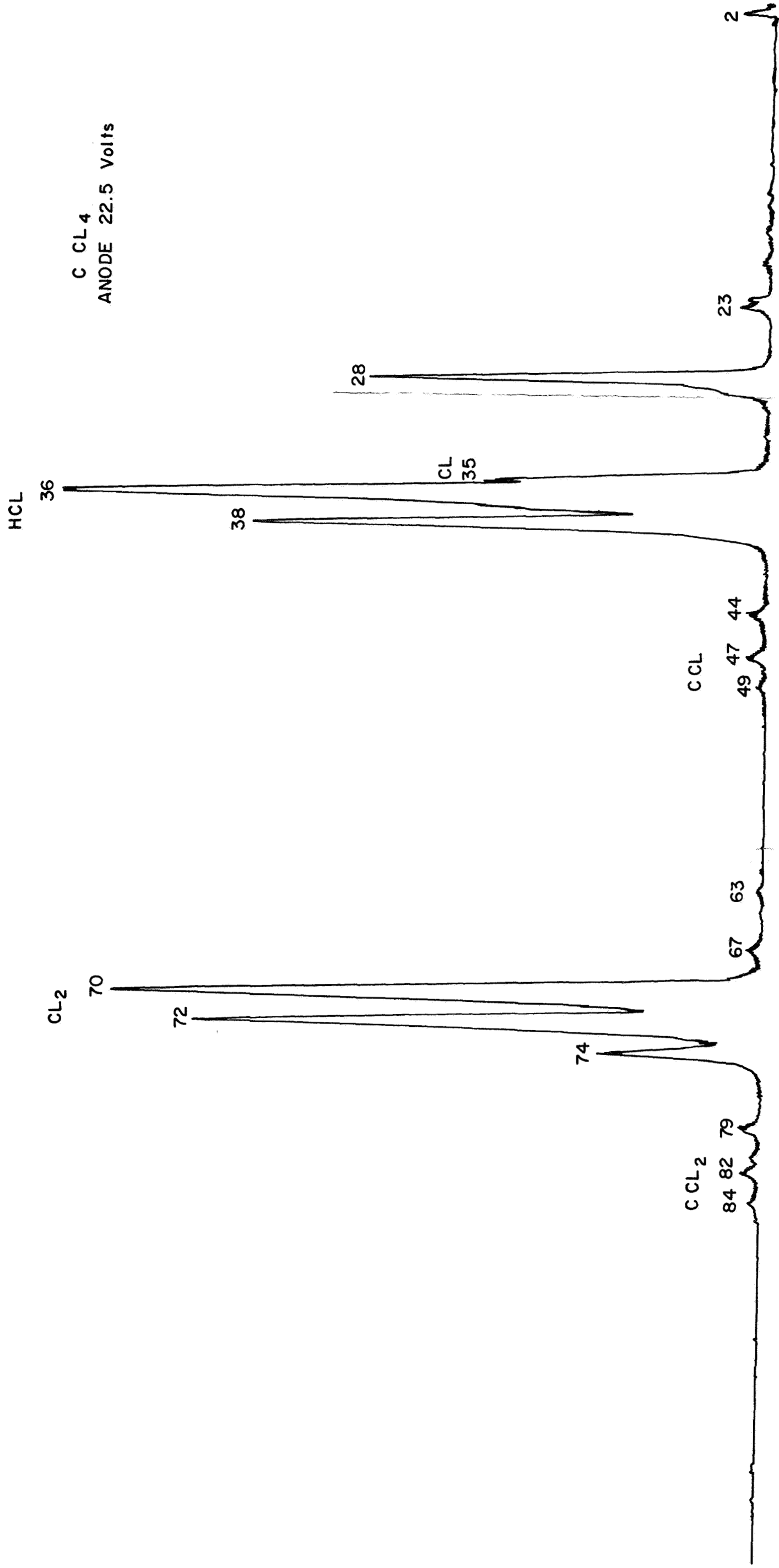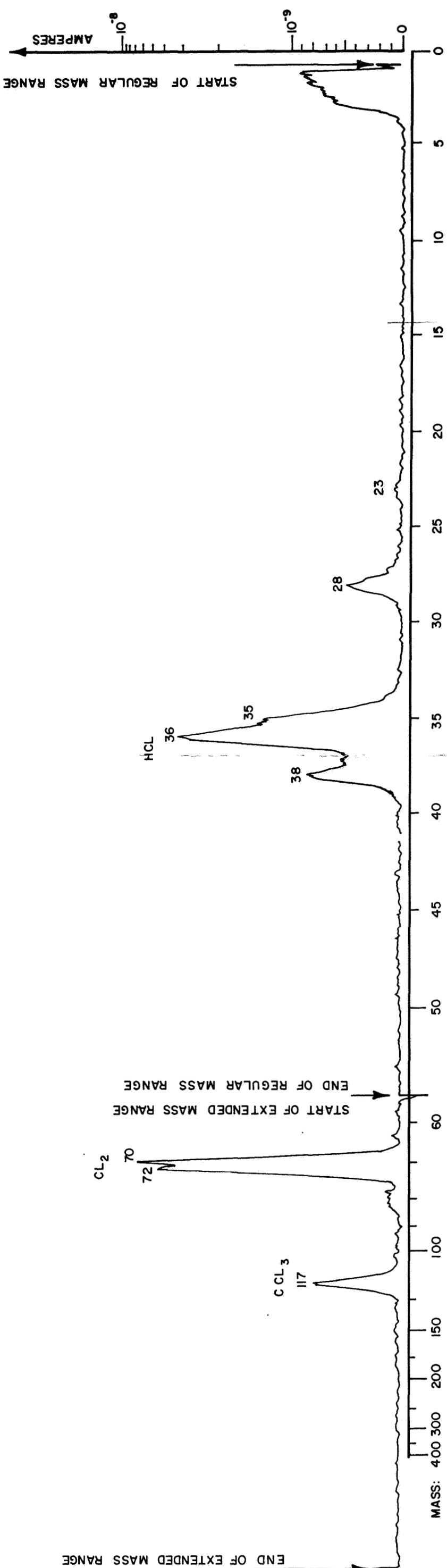
Figure 23. C CL₄ spectrum, slow scan.

55

Figure 24. C CL₄ spectrum, fast scan.

56

LTS69-110S
134

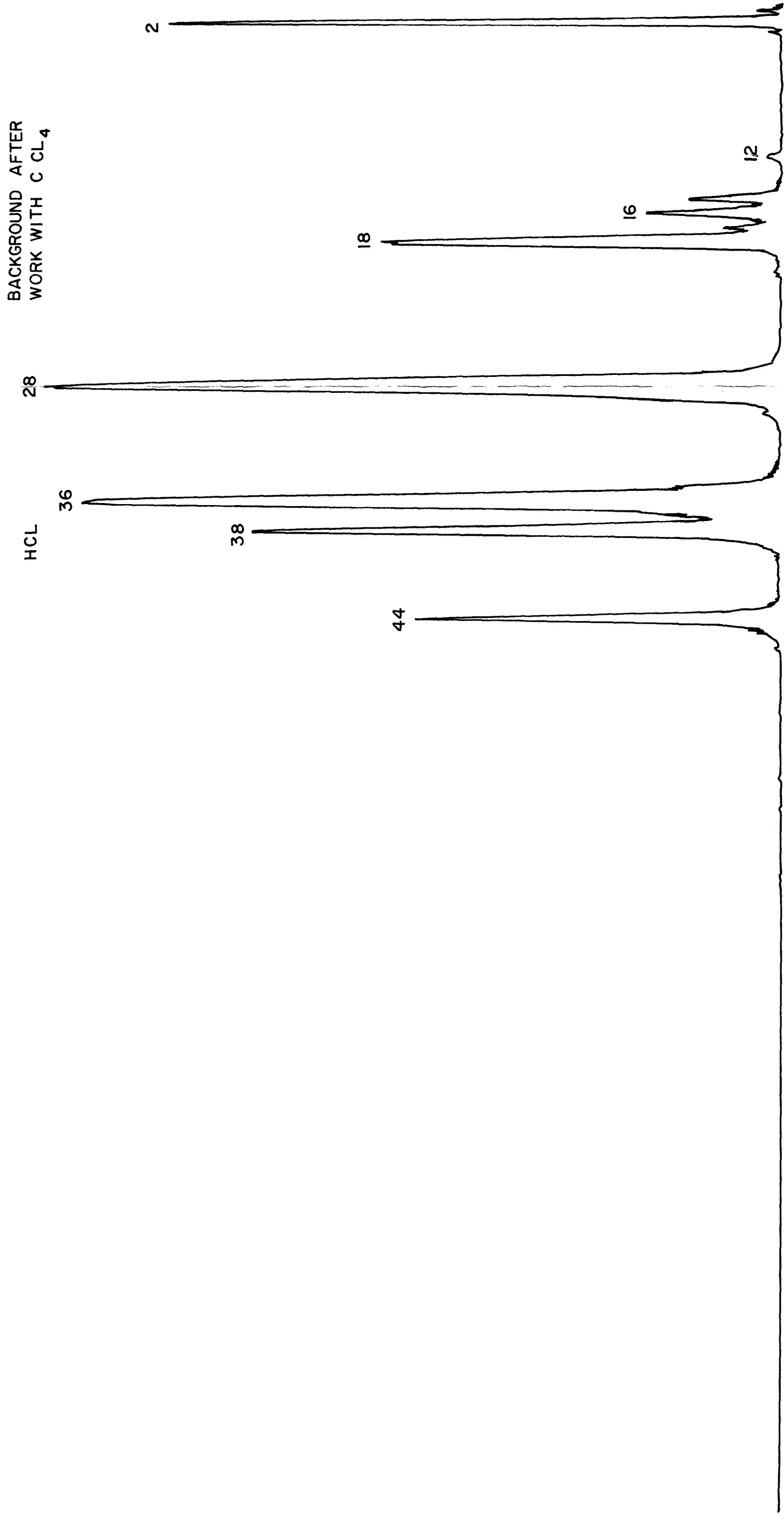BACKGROUND AFTER
WORK WITH C CL₄

2

12

16

18

28

36

HCL

38

44

Figure 25. Background spectrum, slow scan.

57

VALVE OPEN TO 0.18 Torr OF AIR
0.02 Torr LITER INTRODUCED
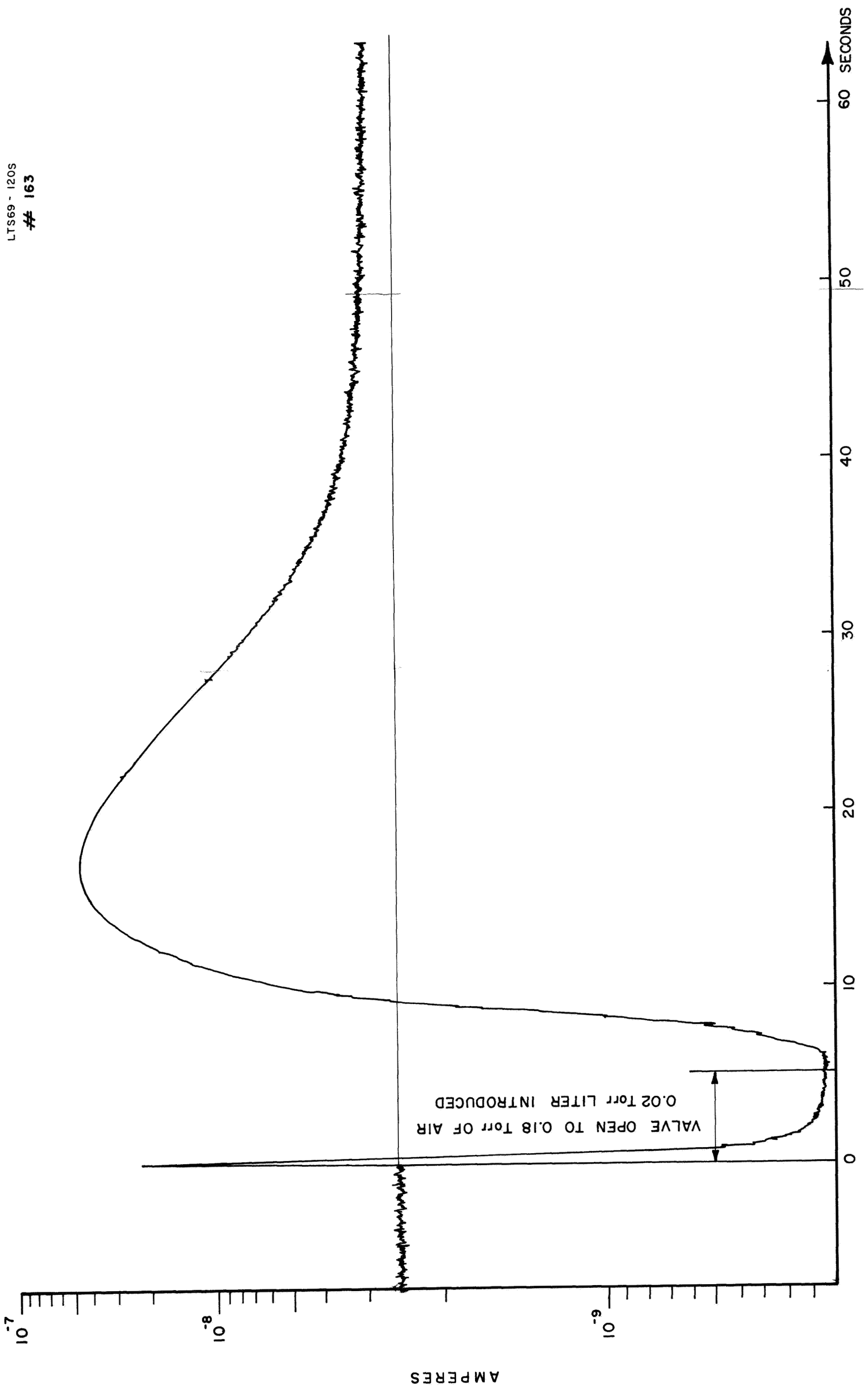
Figure 26. Time variation of 28 peak.

AMPERES

SECONDS

higher than before, which means that nitrogen has not been completely absorbed. The decrease of the peak height between 25 and 30 seconds is proportional to the decrease of the pressure in the ion source. This indicates that the absorption of nitrogen occurs practically instantaneously. This is a definite advantage of the titanium getter pump in comparison to the zeolite cryopump where the absorption process is much slower.

6.3.2 Interference problems between the electrostatic ion pump and the mass spectrometer. — The mass spectrometer of the laboratory model could be operated simultaneously with the electrostatic ion pump. No ions or electrons from the pump have been detected in the mass spectrometer, not even by pulse counting technique of extreme sensitivity. In this case the pump and spectrometer were connected over two right angle elbows and a relatively long and narrow tubulation.

The flight prototype instrument is much more compact which resulted in severe interference problems. In the first version of this instrument it was practically impossible to operate the pump and the mass spectrometer simultaneously. Figure 27 shows two mass spectra which have been obtained with this first version of the flight prototype instrument. The upper spectrum has been obtained with the electrostatic ion pump in operation. The background noise produced by the pump is so large that the mass spectrum can hardly be recognized. The scan of the lower spectrum has been started right after the pump has been switched off. The main peaks, 28, 18, and 17 are now clearly visible. At the start of the scan there is still a large amount of noise which decreases towards the end of the scan. This background noise disappeared about 10 minutes after the pump had been switched off. It is quite unprobable that free ions or electrons could have persisted such a long time. It is more likely that ions which did stick to the wall without being discharged were readmitted at a later time. It is also possible that metastable molecules have been formed which produce light in the moment of return to the ground state.

This interference problem is of no concern for the planned use of the instrument as an ion analyzer in the upper atmosphere, since during the actual rocket flight the electrostatic ion pump would not be in operation and the whole pumping action will be performed only by the getter action of the titanium layer on the wall. All the spectra shown in the previous section have been obtained in this way. Great care was necessary to avoid saturation of the titanium layer if large gas loads were admitted to the instrument. Over pressure may result in severe damage of the instrument. Between measurements the pump has been operated and new active layers of titanium have been deposited on the wall. Therefore, for the laboratory tests of the instrument, it would be much safer if it were possible to operate the pump and the mass spectrometer simultaneously. Considerable effort has been made to determine the cause of this interference and to reduce its magnitude.
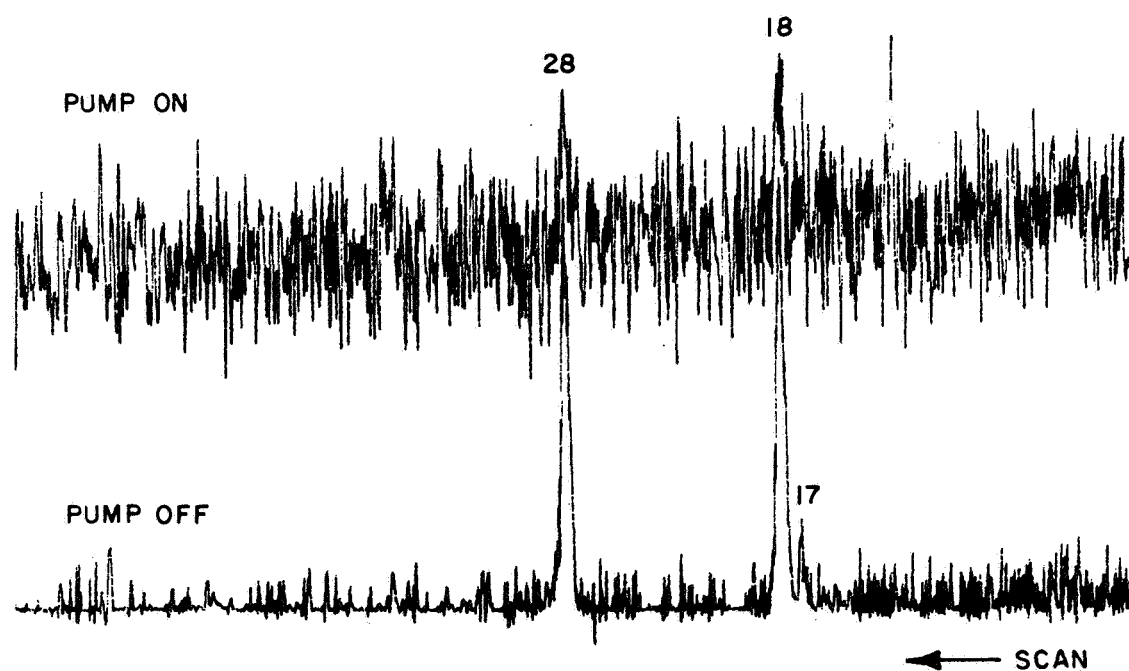
Figure 27.   Pump interference with first prototype flight instrument.

Electrostatic interference was caused by the ac current of the pump filaments and by the ripple of the pump high voltage supply. This interference has been eliminated by inserting the fine mesh 27 (see Figure 1) between the pump and the mass spectrometer. Electrons from the hot filament of the pump did migrate through the grid 27 and were collected by the output wire of the electron multiplier, despite the fact that there was no direct line of sight between the filament and this wire. This happened even if no high voltage was applied to the anode of the pump. This effect could be completely eliminated by applying a bias voltage to the filament of approximately +20 volts against housing. Ions, which are produced in the pump in large numbers, could migrate into the mass spectrometer region and some of them did enter the multiplier through the front aperture. The baffle plate (29) which is kept on anode potential has been incorporated; it retains ions in the pump. The inner tube of plate (61) has also been added to shield the entrance aperture of the electron multiplier against stray ions. Another shield over the exit end of the multiplier has been added and the output wire has been relocated and is now in a better protected position. A large improvement is the result of these modifications which can be seen by comparing Figure 28 with the previous Figure 27. Figure 28 shows an air spectrum with the pump in operation. Even minor peaks at mass 40 and 44 are now visible. However, the interference noise is still not completely eliminated and results mainly in a displacement of the mass spectrum from the base line. This displacement increases with the pump voltage and the pump current and especially with the gas pressure in the pump. Because of the strong field between the baffle plate (29) and the grid (27) or the housing there is no possibility for any charged particles to escape directly from the pump into the mass spectrometer. To explain the observed effect it would be necessary to assume secondary processes in which several charge changes occur. For instance, secondary electron emission from the pump wall, due to ion impact and ionization of the gas between the plate (29) and grid (27) by these secondary electrons. Another possibility is that light from the discharge in the pump may reach the electron multiplier after being reflected several times on the walls and baffles. Further investigations are necessary to determine the cause and eliminate the small remaining interference. If eventually, the pump should be operated during flight, complete elimination of the interference would be necessary. Nevertheless, the improvements are already sufficient to permit operation of the pump during the laboratory tests of the instrument.

6.4 Shock and Vibration Tests

The shock test has been performed with GCA facilities and included several shocks of increasing intensity up to a maximum value of 50 g, applied in axial direction of the instrument. No damage has been observed.

Vibration tests have been performed at Associated Testing Laboratories on 5 June 1968 in accordance with the test procedure for a Nike-Tomahawk rocket. The test report is included in the Appendix of this report. The only damage which could be detected after these tests were broken filaments
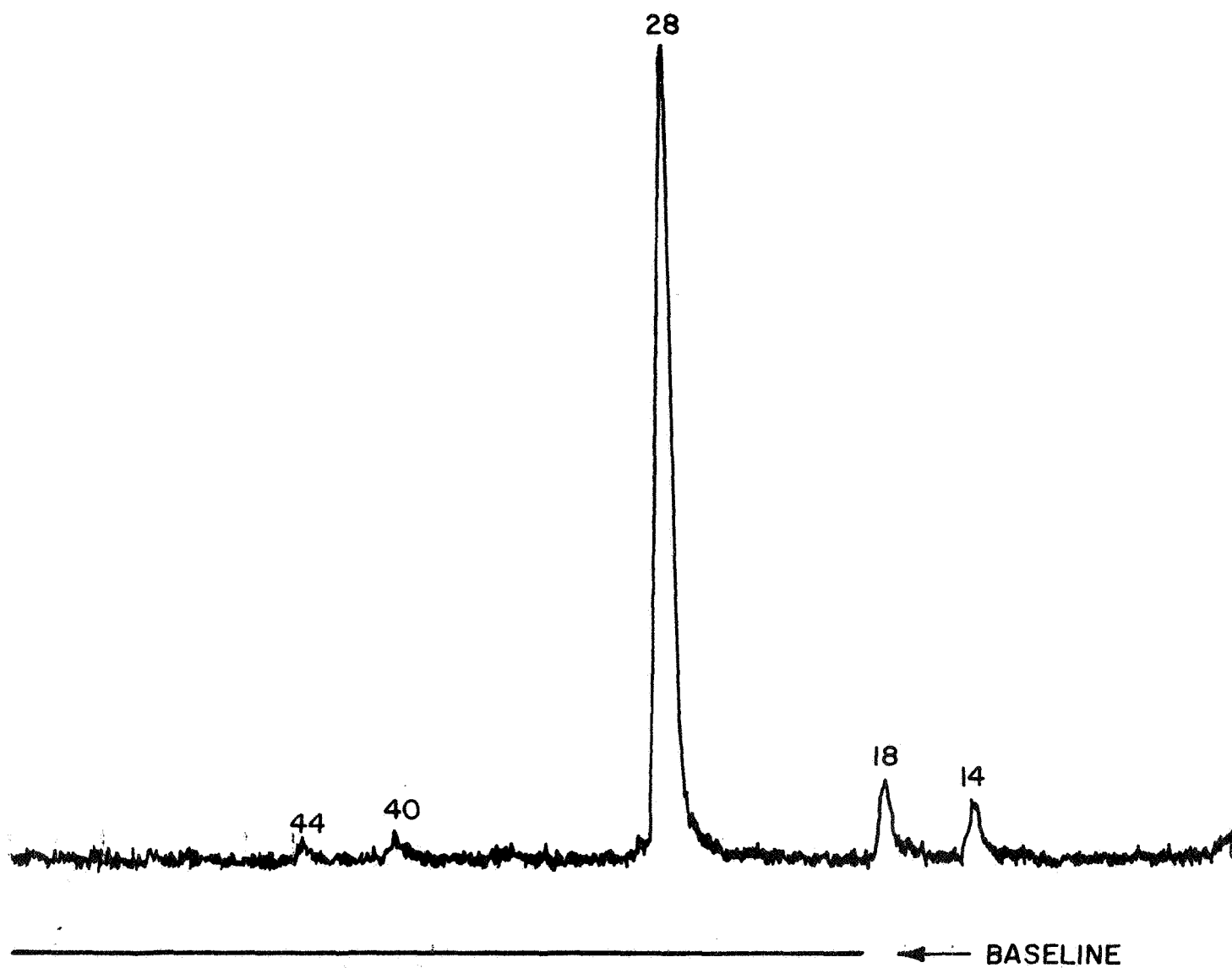
Figure 28. Pump interference with final prototype flight instrument.

in the ion source and in the thermocouple gauge. After these filaments had been replaced, the instrument performed as well as before the vibration tests. The pump filaments and the pump anode did survive the vibration tests. However, it must be mentioned that the pump was not in operation before the test, therefore, no recrystallization of the tungsten has occurred. The tungsten rod of the anode becomes extremely brittle after the pump was in operation for some time. Therefore, the instrument requires very careful handling to maintain the pump in good operating condition for the deposit of a fresh titanium layer immediately before launch. During launch the anode will fracture, but the grids (73) and (27) will prevent broken parts from entering the mass spectrometer section. Therefore, they cannot interfere with the performance of the instrument.

7. RECOMMENDATIONS FOR FUTURE WORK AND IMPROVEMENTS

The instrument is ready for rocket installation. One telemetry channel is sufficient for the transmission of the mass spectra. However, since this instrument is the first one of its kind, it is recommended to monitor the following voltages.

The dc voltages on the rod from pin No. 3 on A5J5. The input impedance of this telemetry channel must be larger than 100 megohms in order to avoid a change of the mass scale.

A small fraction of the voltage on the electron multiplier from pin No. 5 on A2J3. There is no need to check this point continuously, but an occasional check would be valuable.

Signals should be provided to indicate the proper nose cone ejection and the cover release.

Continuous telemetry of attitude sensors is necessary for the quantitative evaluation of the mass spectra.

For the evaluation of the pump performance it is recommended to measure continuously the ram pressure in front of the instrument as well as the pressure in the mass spectrometer.

If in the future more instruments of this type should be needed, it would be possible to considerably reduce the weight and cost. The convenient feature of the present instrument, which permits undestructive disassembly, would no longer be necessary after all laboratory testing has been done and then an all welded construction will be advantageous.

Very important improvements of the instrument are feasible if the ion pump could be operated during the flight. In this case, it would be possible either to open the instrument at much lower altitudes or to increase the size of the entrance aperture and with it the sensitivity of the instrument. The power requirements for operating the pump are small and quite tolerable during the short duration of a rocket flight. The obstacles which have to be solved are the complete elimination of the pump interference and the ruggedizing of the anode structure.

It has been demonstrated previously with the laboratory model that it is possible to detect negative ions and to achieve ultimate sensitivity by a pulse counting technique. Unfortunately, due to the limited funds, it was not possible to incorporate these valuable features into the present flight prototype.

The instrument in its present form is capable to measure relative ion concentrations in the upper atmosphere. In order to obtain absolute concentrations it would be necessary to measure with a Langmuir probe the

total ion concentration, preferably on the same rocket flight. Absolute
calibration of the mass spectrometer itself, including the aerodynamic
phenomena in the shock wave in front of the instrument, is a separate
major task which was not funded in the present contract. The large effort
necessary for such a calibration would only be justified if several instru-
ments of this type will be used for a more thorough investigation of the
ionosphere.

Test Report No. __NT-5587-11__   No. of Pages ____7____

Report of Test on

D REGION SPECTROMETER

Vibration Test

for

GCA Technology Division

Associated Testing Laboratories, Inc.

Burlington, Massachusetts 01803

Date___June 5, 1968___

	Prepared	Checked	Approved
By	J. Cunningham	R. Rainone	T. Jarek
Signed	J. Cunningham	R. Rainone	T. Jarek
Date	6-5-68	6/5/68	6/5/68

Administrative Data

1.0 Purpose of Test:

To verify the physical integrity of the submitted D Region Spectrometer through vibratory excitation.

2.0 Manufacturer:

GCA Technology Division
A Division of GCA Corporation
Bedford, Massachusetts

3.0 Manufacturer's Type or Model No.:

Unspecified

4.0 Drawing, Specification or Exhibit:

Specification entitled "Flight Acceptance Test for Nike Tomohawk"

5.0 Quantity of Items Tested:

One (1)

6.0 Security Classification of Items:

Unclassified

7.0 Date Test Completed:

May 22, 1968

8.0 Test Conducted By: Associated Testing Laboratories, Inc.
NEW ENGLAND DIVISION

9.0 Disposition of Specimens:

Returned to GCA Technology Division

10.0 Abstract:

The submitted D Region Spectrometer was subjected to a Vibration Test in accordance with Tables I, II and III of the above referenced Specification. Applied vibration consisted of Sinusoidal at up to 7g's peak and Random at up to $0.05g^2/Hz$. Vibration was applied over a frequency range from 10 to 2000 Hz in each of three mutually perpendicular axes. There was no evidence of physical damage to the D Region Spectrometer as a result of the vibratory excitation.

Report No. NT-5587-11

Page 1

CALIBRATION AND STANDARDIZATION

Each laboratory division maintains a Calibration and Instrumentation Department with control over the wide range of electronic, mechanical and environmental test equipment in inventory at the facilities. The calibration procedures are based on the requirements of Specification MIL-C-45662. All working instruments in the laboratory are periodically calibrated by means of calibration standards which are not used in the performance of tests. These calibration standards are maintained in a calibration and instrumentation area. Further, the calibration standards are periodically calibrated by either their manufacturers or by an approved outside source.

When the calibration standards are re-calibrated, a certification is obtained which not only details the standards' accuracy, but also specifies that the calibration of the equipment is traceable in an unbroken line to the National Bureau of Standards. These certifications, as well as the individual equipment history cards, are on file at each laboratory division. In addition, a "calibration due" sticker is placed in a prominent position on each item of equipment. It is incumbent upon each test operator to examine the sticker before using any equipment to insure that the equipment will not be due for calibration during the test period.

In general, the laboratory standards used for the calibration of the working test equipment will have an accuracy equal to or greater than ten times that of the working standards. Typical calibration frequencies for test equipment are as follows:

Item	Calibration Period
1. Galvanometer Type Laboratory Quality Meters	six months
2. Vacuum Tube Voltmeters	one month
3. Impedance Bridges	yearly
4. Electronic Counters	six months

CALIBRATION AND STANDARDIZATION

Item	Calibration Period
5. Oscilloscope Preamplifiers	three months
6. Vibration Systems	three months (with spot - calibration - prior to use)
7. Signal Generators	three months
8. High and Low Temperature Chambers	two months
9. Multi-Testers	three months
10. Pressure Gauges	six months
11. Calibration Standards	yearly
12. Shock Machine	six months
13. Recording Instruments	Prior to use
14. Precision Scales and Balances	three months
15. Special Purpose Test Equipment	three months (unless otherwise specified)

LIST OF APPARATUS

Item	Manufacturer	Model No.	Accuracy	Calibration Date	Date Due
Vibration System	Ling Electronics Corporation	335	Freq.±2% Ampl.±5%	5-20-68	8-20-68
Automatic Spectral Density Equalizer Analyzer	Ling Electronics Corporation	ASDE-80	±5%	5-15-68	6-15-68
Accelerometer	Endevco Corporation	2215-E	±5%	3-14-68	6-14-68

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TEST PROCEDURE

The submitted D Region Spectrometer was subjected to a Vibration Test
in accordance with Tables I, II and III of GCA Specification entitled
"Flight Acceptance Test for Nike Tomahawk". The following is a
description of the test as it was performed.

The D Region Spectrometer was securely attached to a Vibration Test
Fixture which was, in turn, securely fastened to the head of a
Vibration Exciter. Figure 1 at the end of this Report shows the
test specimen mounted for Vibration. The test consisted of three
parts; Sinusoidal Survey, Sinusoidal Sweep and Random Frequency
Vibration. Vibration was applied in each of three mutually perpen-
dicular axes and vibration was completed in one axis before going
onto the next. The Vibration Test was performed as follows:

Table I

Survey Flight Level Sine Sweep

Axis	Frequency Range (cps)	Level (g.0 to peak)	Duration *
Thrust Z-Z	10 - 2000	1g	*
X-X & Y-Y	10 - 30	1g	*
	30 - 2000	.5g	

* Sweep Rate 1.5 Octave/Min.

Table II

Sinusoidal Logarithmic Sweep Vibration
Test Schedule

Axis	Frequency Range (cps)	Level (g.0 to peak)	Duration * (min)
Thrust Z-Z	10 - 18	1.5g	*
	18 - 85	5"/sec	
	85 - 2000	7g	
Lateral X-X & Y-Y	10 - 144	3"/sec	*
	144 - 2000	7g	

* Sweep Rate 4 Octave/Min

Table III

Random Vibration Test Schedule

Axis	Frequency Range (cps)	Test Duration	PSD Level (g^2/cps)	Acceleration (g - RMS)
Thrust Z-Z	20 - 2000	20 sec	.05 g^2/cps	10g
Lateral X-X & Y-Y	20 - 2000	20 sec/axis	.03 g^2/cps	7.6g

Following completion of each part of Vibration in each axis, the D Region Spectrometer was visually examined for evidence of physical damage or deterioration.

TEST RESULTS

There was no evidence of physical damage or deterioration as a result of the Vibration Test. Following completion of the test, the D Region Spectrometer was returned to GCA Technology Division for further evaluation.

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